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THE PROFESSION OF ORE-HUNTING.[1]

AUGUSTUS LOCKE.

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THE NEW MINING GEOLOGY.

A 1920 bulletin of the National Research Council lists 297 commercial research enterprises in the United States. Of these, many are scarcely of the true research character. Others, like that of the General Electric Company, are magnificent in the quality of their achievement. Although, then, there exists no such research development here as in the pre-war Germany, with its many institutions to our one, there is enough to show that American industry is beginning to find the scientific method to pay.

Notable from the standpoint of geologists is the absence in

[1] This paper has had the benefit of criticism by Mr. William Burns and Mr. Guy N. Bjorge.

the bulletin above mentioned of the name of a single research devoted to commercial mining geology. Indeed, the fact is that commercial mining geology has failed, so far, to reach the research stage. Appliers of technique it enlists in large numbers; originators it enlists but rarely. Not standing out as the one best means for ore discovery, it has failed to gain financial support for broadly planned experimental operations.

The reasons for this condition in mining geology are complex. Prominent among them is its inconspicuousness. Its results merge themselves slowly into the general development policy of the mine and fail to speak out sharply and eloquently. It gains fame slowly, therefore, in the public mind, and while many know the value of geology in oil exploration, few know its value in mining.

There is, however, another and more fundamental reason. So easy have the metal-bearing deposits been to find that fine methods have been unnecessary. Rules of thumb and sinking on surface ore have produced in the United States the greatest mining industry in the world. Just as we have lived without the urgent need of shrewd foreign policies, so we have lived without the urgent need of fine ore-hunting policies. Lacking both, but provided with great natural riches, we have had a supremely successful history. Naturally enough in our time of easy prosperity, the obvious methods have seemed sufficient.

But this reason is beginning to disappear. The time has come when the discovery of new ore is becoming difficult. There are probably few great deposits in the United States still to be found by prospectors meeting ore or plain indications of ore at the surface. And guess work is so costly that it requires the raw excitement of sudden success to persuade the business man to pay for it. The time, then, has come for finer policies of ore-hunting; the time has come for a new commercial geology.

With the change in requirement, the new geology will be fundamentally of a research character. It will go somewhat parallel with the Geological Survey, but with an industrial aim. It will have at its command the best existing technique. It will do the

work thoroughly, we may hope, through groups of specialists—chemists, structural geologists, and mineralogists. Its workers, on their part, will assume a rugged attitude in the application of their art to human affairs. They will possess clearly recognized functions. When ore is to be sought, the shift boss and mine foreman will seek their advice, and the present lack of harmony, based largely on mutual disrespect, will decrease. In the course of time their skill should reach a plane seeming now inconceivably high.

Whether the new geology will come late or soon will depend to a considerable extent on the geologists themselves. They can wait and allow the research spirit to creep into the profession from other industries. Or, they can, by able efforts, stimulate that spirit within the profession itself. They can preach its necessity; refuse engagements conceived on a meager scale; insist, when conditions are right, on money for thorough work; undertake researches of their own on matters of commercial interest, such as leached croppings. They can, furthermore, destroy the charlatan, betray the parrot that talks like a man, and distinguish in their own work between the lucky guess and the well-planned technical achievement.

The time is here for a change, and it is fitting for us to consider what part we may play in that change.

TWO DEPARTMENTS: TECHNIQUE CREATION AND APPLICATION.

An outstanding impediment in mining geology is the lack of a special technology for ore-hunting. Geological description and explanation exist in large quantity. But geology conceived as a *guide to ore* is essentially without a literature. Scarcely an effort has been made, for example, to indicate how the lore of geology can be made a basis for the judgment of leached cropping. "Scouts" are in action by the score; but they must depend for such judgment on individual experience. A good half of the needed equipment, namely, the specific technology, has been neglected—it is as though doctors were provided with

books only on physiology, or engineers with books only on physics.

For the removal of this impediment, mining geology needs an additional kind of commercial worker. It needs, in fact, not only the *applier* which it already has, but also the *inventor,* the one working in intimate coöperation with the other; the one providing the foundation knowledge and the other using that knowledge in the daily operation of the mine.

The functions of these two sets of workers are supplementary and they will seldom be combined in one man. For, in the first place, so much concentration is required in each that one man, though temperamentally fit, could seldom handle both. And, in the second place, a temperamental fitness for both would rarely exist in one man. In a measure, the very qualities that fit the scientific geologist for the solution of large problems may unfit him for the daily human contact and routine involved in actual mining. And, on the other hand, the staff geologist, the applier, needs an additional set of qualities, partly executive in character, enabling him to adapt his knowledge to the human and operating exigencies present in the particular mine.

The inventor, obviously, will be an innovation in commercial mining geology. For his further specification, let us recollect a type of character which in mining is more familiar, namely, that of the executive. Defining this, we shall have something with which to compare the other.

The executive, then, of a kind which every one will recognize as effective and characteristic, has a deep down sense of values which he knows to work. Partly this is perhaps instinctive; partly it is based on experience in quick decision. But whatever its origin, it results, almost without conscious effort, in an ability to meet emergency after emergency with positiveness and ripe common sense. In the management of a body of men, a single day may require of it a score of important decisions made on the moment, face to face with particular individuals, and all essential to the harmonious operation of a complicated enterprise.

Chiefly, it seems, this executive faculty rests on an ability to read exceptionally well the content of another's mind. And it is in this aspect that we take especial interest in our comparison with the needed qualities of the geologist. For, while the task of the executive is chiefly a *human* one, that of the geologist is chiefly a *technical* one; while the executive must be capable of quick, effective action, the geologist cannot, in general, be other than deliberative—there is no instinct on which, for the solution of geological problems, he can safely depend. Between the two sets of needed qualities there lies a clear contrast.

But it will of course be understood that the full contrast is seldom, in practice, realized. However much the executive leans on the faculties mentioned, he will seldom escape an important ingredient of deliberation. And the geologist, for his part, will be sorely inconvenienced unless he has at least a moderate facility in promoting action on his ideas. Furthermore, the sharpness of the contrast will vary with the kind of work to be done. The inventor may be almost a pure technician. The applier, as was suggested above, may well be half executive; in the ideally desirable form, he has the rare combination of executive and technical abilities which would permit him to develop into either a good geologist or a good mine superintendent, as occasion prompted.

These considerations indicate, as was suggested above, that the inventor geologist has qualities unusual in commercial mining work. But out of this fact arises a difficulty: the mine operator is prejudiced against "scientific" ore-hunters; he has found them unsatisfactory because they refuse to stick to the problem. It will be no easy matter to persuade him that his opinion is wrong. Nor can he, indeed, be blamed for his opinion. There are plenty of men in geology who feel at liberty to gloss over vagueness with scientific jargon. And there are others, not at all vague, who speak and live by the book alone. These, in the eyes of the miner, give science a hue of futility.

It is of course true that the man of neither class is a scientist; rather, he is the "cap and bells" of science "that marks its

opposite." It is true, moreover, that the scientist of the genuine sort, once committed to the problems of ore-hunting, will show that ability to go to the point that is an essential no less in science than in business; he will carry conviction with the coldest business man. But however true this is, the difficulty of the operator's antagonism remains a real one.

In what way will this difficulty have effect? Chiefly, as seems likely, in hindering appropriations for inventor geologists. But why should the mining companies make these appropriations? Why not the government? And why not private institutions already existing?

The money will come from the mining companies, because, the world over, commercial research is accomplished by commercial institutions. We cannot more reasonably expect an ore-hunting technology from the government or from the university than we can expect a railroad-operating technology. If geology is to have an ore-hunting technology within a reasonable time, the mining companies must stimulate it and pay for it. That they will do this is to be confidently expected; for when they need a thing they are in the habit, not of waiting for it to fall from the sky, but of planning vigorously to produce it.

This brings us to the matter of chief interest and that which constitutes the chief reason for this paper. It is especially the geologist's task to prove by results that science is needed in ore-hunting. This task, though difficult, should show progress through the correction of certain outstanding faults of the geologist himself—faults consisting largely in vagueness of purpose and conception. It is to the consideration of these faults and to the difficulties in getting appropriate men that this paper will devote its principal energy.

DEFINITENESS, BASED ON KNOWN HABITS OF OCCURRENCE.

In the search for vagueness in any scientific activity, we shall do well to inquire if there are not directions in which the mind, unless it be restrained, tends naturally to vagueness. We may, indeed, be certain that any direction of thought whatsoever will

be followed if it is gratifying. Let us seek, then, an important gratifying vagueness, for in that, if we find it, we shall detect a danger to mining geology.

There is, by all means, just such a gratifying vagueness in the habit of depending on the apriorism. For the mind seems by nature to love the apriorism. Of a hundred citizens there are not three whose thoughts on the North Star have any fundamental concreteness; not three who, bereft of the whip of scientific influence, would not lapse into coarse superstition.

For the mind takes far less gracefully to the inductive than to the deductive method. Perhaps this is because it has had little exercise in the inductive method. But whatever the reason, it loves to sit and ponder on the materials directly at hand; it will not naturally go out for more materials. It has to be whipped to action.

This, the reader may say, is old. But it is none the less a vital consideration in this discussion; for we are especially concerned with the causes of vagueness in commercial mining geology, and of such causes the habit of depending on the apriorism may be regarded as one of the worst.

What, then, is the apriorism in geology? The *apriorism,* as the term is used here, determines a particular effect through rules focused from afar on the specific problem. Thus, in a leached cropping over unexplored sulphides, we usually find a few residual spots of sulphides. Now and then in the Southwest these are pure chalcocite and the question arises as to whether there could have been a residual concentration of chalcocite in proportion to pyrite. In other words, is the sulphide lying at the surface relatively richer in chalcocite than the sulphide which will be encountered lower down?

The apriorist might undertake to answer this question on the basis of his general knowledge of the relative solubilities of chalcocite and pyrite. The empiricist, on the other hand, would use the shortest chain of reason and would depend as closely as possible on actual comparisons between sulphides residual in croppings and those known lower down. For him, evidence

from other districts, and especially from this particular district, would count most heavily. He would seek actual examples and collect evidence of actual residual enrichments. While, then, there would be no neglect of the reasons for the conditions found, these reasons would act mainly as a stimulus for observation; and recommendations regarding exploration would depend principally, not on the reasons, but on the concrete or empirically derived facts. The argument would rest, not so much on geology in the larger sense, as on geology in the sense of ore habits, and the empiricist would lay his hands on the evidence and get his proofs *as close to home as possible.*

These considerations suggest a scale of specificness in which evidence may be advantageously classified.

The scale follows:

1. The apriorism.
2. The type habit.
3. The district habit.
4. The ore-body habit.

To cut a geological report into its several reasons and assign to each its place in this scale is an illuminating exercise. For while an ore-body habit may be a reliable guide, an apriorism will be effective only by accident; it will be only remotely possible, like an attempt to assemble a watch with a pair of wooden pointers. And even the type habit will not be too minutely trusted, for the individuals of a type resemble each other only in selected particulars and threaten momentarily, even there, to rebel. Knowledge of a single concrete fact, such as the depth of leaching shown in a shaft or the degree of enrichment shown in a half dozen specimens, is more useful in the judgment of a particular ore-body than a wagon load of remoter knowledge. A report, shown to stand on such remoter knowledge, may with safety be rejected.

Obviously, what is needed is the quantitative or statistical method. This method, in contradistinction from the method just now designated as apriori, is illustrated by the following

examples derived from the experience of many geologists and engineers:

1. For the most part, disseminated copper deposits lie within two thousand feet of the borders of igneous stocks; a considerable number lie within one thousand feet.

2. In these deposits, if the proportion of pyrite to copper-bearing sulphides is, say, several to one, the copper is likely to be non-commercial. If it is, say, one to one, the copper is far more likely to be commercial. Therefore, in the judgment of a cropping, the evidences of abundant pyrite are important.

3. Secondary sulphide enrichment starts usually just below the limonitized capping, is often, though not always, most complete at the point of starting, and most often fades out gradually within five hundred feet.

4. Secondary sulphide enrichment tends to go deeper along well-defined fractures, whether these are earlier or later than the primary mineralization.

5. No constant difference has been established between croppings over ore enriched to a depth, say, of fifty feet, and those over ore enriched to a depth of three hundred.

6. The greater the proportion of copper-bearing sulphides to pyrite, the greater the tendency, other things being equal, for oxidized copper salts to be stranded in the limonitized capping at the expense of the enriched zone. (The obvious importance of weighing this consideration against No. 2 above constitutes an example of the dangers of apriori reasoning on the basis of a single hypothesis.)

7. The judgment of leached croppings over disseminated ore of mixed pyrite and copper sulphides, and their distinction from leached croppings over material of a little less than commercial copper content, is, in the present condition of our technique, a difficult matter. A decision, therefore, based on the character of the capping alone should be accepted reluctantly.

8. On the other hand, when specimens of the assured sulphide parent are accessible (and they often are so even on undeveloped prospects) and careful comparison with corresponding capping

denotes plain capping distinctions, empirical evidence is available and justifies reasonable confidence. Patient search for such sulphide parent specimens is therefore an important early step.

9. The disseminated deposits too low in copper to be commercial are many times, probably a hundred and perhaps a thousand, as numerous as those of economic grade. Therefore, a given deposit can be condemned, unless (*a*) the next step in its testing is exceedingly cheap, or (*b*) it yields some positive reason for the belief that it is commercial.

10. A change of rock, such as monzonite to limestone, limestone to monzonite, or andesite to monzonite, is likely to affect the values; and there is a high degree of probability that if important ore exists in the rock exposed, the change will make it poorer. But the only safe rule is to rely on the known local habits.

11. Typical contact metamorphic ores (*i.e.*, those having garnet and other lime silicates with magnetite, hematite, etc.) tend to spottiness, usually have a high development cost, and are likely to yield high cost copper (15 to 30 cents per pound). They usually make "grief mines"—that is, mines operating only when copper prices are above the average. They are little worked below a depth of five hundred feet, not because they do not extend below this depth, but because their cost of discovery and exploitation there has become prohibitive.

12. A conjunction of mineralized fractures, such as two veins, has an effect on ore occurrence varying widely in various districts and various ore-bodies. The only conclusions warranted are usually those based on known local habits.

13. Dense elastic igneous rocks, such as fine-grained basalts, usually carry "spotty" mineralization, unless the mineralization is guided by strong fractures. In such rocks widespread disseminated copper ores are distinctly less likely to occur than in schistose or coarsely granular rocks.[2]

[2] Three additional "rules," of a sort which can scarcely be termed geological but which are worth quoting because they typify a sort of lore with which the geologist should be familiar, are as follows: (1) Bottom levels, because of

These examples illustrate, of course, rather concrete knowledge—not, it is true, as concrete as much of the knowledge derivable regarding a given ore-body, but still usefully definite. And though the conclusion that such knowledge is necessary may seem so reasonable that no one would question its soundness, there is nevertheless great need that it be emphasized. For we are not used to empirical geology; most of our geological exercise is not such as to enforce a sharp checking up with the facts. The story of the famed teacher judging a tidewater mine a quarter mile off-shore is, in fact, only an extreme example of what geologists are tempted repeatedly to do. Even in such phases the apriori method is by no means unfamiliar. We repeatedly base conclusions on shallow apriori reasoning. And this includes not only the "parlor" geologist, but also the staff geologist at the mine. For, while the former is so gratified with the images of his mind that he takes no pains to check them against the concrete occurrence, the latter has few images to stimulate his power of observation. There is, indeed, no more offensive apriorist than the squinting, one mine technician, who never looks beyond for the geological setting.

We generalize vaguely. Here is disseminated copper ore in monzonite; when it reaches the limestone which we know to exist at a depth of two hundred feet, it should become rich, so we say, for limestone is more easily replaced than porphyry. Yet the plain facts are that limestone in contact with disseminated ore in igneous rock sometimes makes richer ore and sometimes poorer, and sometimes no ore at all.

incompleteness in the exploration there, often look bad without proving a decrease in size or grade. (2) The prospector of the old time type knows, through patient study of float, etc., how to pick out the obviously good showings. A prospect, therefore, which has, through the soil, irregularly spaced holes showing obviously good looking stuff, is rather certain to present a better aspect than it would if the holes were placed elsewhere. And a bulky deposit explored, not by a rectangular pattern of workings, but by crooked drifts and crosscuts, is likely to yield unduly high assays; for the prospector was probably "nosing" his way along after the better streaks. (3) "In ground known to be highly productive (where the rewards of a discovery are high) the factor of accidental discovery is an important one and the geologist may not properly object to a considerable amount of blind exploration."

Such vagueness of conception is out of step with business activity and it has no place in mining geology; there is nothing practically more futile than action based on generalization without a proper conception of the *degree of doubt*. The particular hypothesis, as, for example, that of increased richness in the limestone, can be used as an apriori basis of reasoning only after all other possible hypotheses have been weighed and rejected. If he be thoughtful, the apriorist will involve himself in a welter of reasons. If he be unreflecting, he will, with shallow energy, devote himself to a particular hypothesis. And any conclusion based on the apriori assignment of a dominant position to a single influence is subject to suspicion. Indeed, it may with safety be rejected; its chances of being sound are not one in a hundred.

For any geological result, such as an ore-body, obviously rests on a complex of conditions. Only through a knowledge of groups of such conditions commonly lying together can certain single causes become significant and can the reasoning be sufficiently simple to be effective. Given known groups of conditions, it is the variations that count; given disseminated copper mineralization, there is at once a considerable body of knowledge regarding the deposit in question, and it is the variations from the average types that particularly concern us and that serve especially as a basis for our judgment.

Knowledge of these groups and of these variations will not be furnished by the apriorist. It is the empiricist who will transact most of our business for us. He, in place of vague generalization, views the ideal diagram with cold regards and uses it only after marking it with "beware" signs. And to define probabilities he employs the statistical method. He knows that deposits of the "shallow vein type" are commercially important below one thousand feet in only two instances out of twenty; that, therefore, in this particular deposit the likelihood of ore going deep is small. All day long he will have the habits of real ore-bodies to whisper their counsel in his ear. It is surprising how soundly and quickly he will bring the flying hypotheses to

earth and pick those having the greatest practical probabilities. To the apriorist, anything is possible. To the empiricist, only those chances seem worth attention which sit nicely in the scope of likelihood. Through his touch with ore-bodies he gains a faculty of keen judgment and selection which may seem almost instinctive and which produces results astonishingly shrewd and effective.

The empirical "rules" cited above and the many others proved useful could not, it is true, have been established without apriori reasoning. There is nothing like an hypothesis to quicken observation and nothing more essential than an equipment of ideas in advance of field work. Abstract thinking must, indeed, supply the large ideas, but only concrete study can define those large ideas which accord with the habits of ore-bodies; can define, in other words, those conditions likely to serve in mining. It is the apriorist who, half empiricist, will constantly challenge his thoughts and measure them against observed conditions, that is admirable; he is the ideal mining geologist.

It is not such as this, but the chronic and exclusive apriorist, whom we would discourage; the "nerveless sentimentalist" who never applies his thoughts in action; the pedant, who spends his time "motivating" facts, like a man "explaining" his conduct; the fluent speaker with his diagrams, who gains full gratification from thought and conversation alone; "the intellectual" who reasons a fault at the base of yonder hill, but never goes out to see. These are perforce unsound; however gracious of manner, however brilliant of mind and diction, they can show but a foolish ineptitude beside the seasoned ore-hunter.

The desirable combination is an active mind to supply hypotheses and a relentless activity to test them out. Above all things, the need is for men who possess positive and imaginative knowledge of mining districts by the score. Seldom will a geologist be well trained and seldom will he be convincing till he has spent a number of years doing important work in district after district. The geologist needs, not so much extraordinary intellect, as shrewd schooling in half the mines of the country.

Turgenev and Emerson have some thoughts pertinent to this general subject. Turgenev, in "Smoke," says:

"Let a dozen Englishmen come together, and they will at once begin to talk of the submarine telegraph, or the tax on paper, or a method of tanning rats' skins,—of something, that's to say, practical and definite; . . . but let a dozen Russians meet together, and instantly there springs up the question . . . of the significance and the future of Russia, and in terms so general, beginning with creation, without facts or conclusions. They worry and worry away at that unlucky subject, as children chew away at a bit of india-rubber. . . ."

And Emerson:

"Metaphysics is dangerous as a single pursuit; . . . the inward analysis must be corrected by rough experience. Metaphysics must be perpetually reinforced by life; must be the observation of a working man on working men."

And, to come down to our own time and our own specific problems, W. M. Davis says:

"Safe interpretation needs the conscious application of the scheme by the observer in the field."

THE THEME OF ORE HUNTING.

In addition to the excessive use of apriorisms, there is an important source of vagueness in the failure by the geologist to confine himself to the actual purpose of his work. What, then, is this purpose?

Clearly it is not literary, nor scientific, nor the gratification of the geologist through the exercise of peculiar faculties which he may have. It is *the supplying of cheap information.* It is chiefly the convincing development of the questions: "What are the steps indicated toward the discovery of ore?" and "Does the possibility of ore discovery warrant the next indicated step?"[3]

Most reports, then, representing geological results, have a common major theme—the possibility and cost of commercial ore. This theme in many cases may be narrowed and made more

[3] There are, of course, adaptations of this purpose, such as aid in the placing of workings to miss bad ground, in the planning of mine lay-outs and in the control of mine water.

specific. Thus, in the particular prospect there may be established inexorable requirements, such as probable size, grade, amenability to metallurgical treatment, and accessibility to market, in default of which the property may be condemned. And of these requirements, while some may yield sharp, quantitative conclusions on empirical evidence, others, offering no ready answer and needing refined methods of reasoning, may at best be indeterminate.

It is the business of the report, while giving a good account of the reasoning, to dispose summarily of those considerations regarding which the conclusions are definite and readily reached. And it is the business of the report to focus its attention on the remaining considerations. For example, a prospect with the size of its ore clearly shown by leached croppings may have the grade only vaguely determinable. Knowledge of the grade is, of course, a necessity. There is no use discussing size at length if the size is fairly obvious; there is no use coming to metallurgy; and almost the whole energy of the report can therefore apply to considerations of grade. Grade is the chief theme. Any report on this particular prospect which wanders far off into considerations other than grade is commercially a poor report, for *it is answering questions that have never been asked.*

The observance of the principle here suggested can actually give to the report an artistic character. First, we strip off matters which require but little consideration, and then we employ all our energy in an attack on that consideration or those considerations which are pertinent and which require care for their successful handling. We never make the mistake of the chronic precisian; we save our pains for the dominant theme. And in the report there is scarcely a turn where the dominant theme cannot be developed, and no opportunity should be missed for its development; every sentence should be purposeful. In a history of the prospect, for example, we produce, not a chronicle of events, but an explanation of those events. Perhaps the prospect has been long known and frequently examined. Why has it not been acquired by a powerful company? Why is it idle? Those

are the questions which we shall have to answer. How did the ore happen to be discovered? By accident? Because ore cropped? Because the prospector panned the gravel, or with patience scratched the surface for float? The history to go before the cold eye of business may well be made significant. For we cannot convincingly discuss it without considering the question, "If past operators have made a failure of this property, how in the name of logic are we to contrive a success?"

But through some perverse turn in his make-up, dependent, perhaps, on the variety of attractions offered by his training, the geologist finds difficulty in sticking to his theme. Reared aloof, without intrinsic interest in ore, he may regard an ore-body as a detail in the geological composite and may find leached capping no lovelier than gray rock. And he may forget that geology in his case is an applied science, and that the important matter is: "What does this mean in terms of ore?" Whatever the reason, he does in general answer questions that have never been asked, or, having real purpose in a discussion where the reader lacks interest, he fails to explain that purpose; he fails to create in the reader an appetite for that especial piece of information. He concerns himself repeatedly with interesting apriorisms, when he should know the shortest chain of reason is the best; when he should know that concreteness—reference to specific habits of districts, mines and ore-bodies—must be the basis for sound conclusions on particular ore-bodies. He forgets that his business is not that of geologist, but that of regarding the several articles of geological thought as *guides to ore*. In a few minutes of conversation or a few pages of a report he reveals his incompetence. He is as likely as not to emerge from a trip through a mine knowing much of the rocks, but little of the amount of visible ore and of the chances for further ore. He shows no realization of the fact that he will never be highly useful till the investigation of these questions becomes the principal theme of his geological activity and till the other matters are of interest to him chiefly as they contribute to that theme.

In thus failing to stick to his job, the geologist often commits

the unpardonable error of introducing unnecessary controversial matter. He may generalize to the effect that a drop in water-level brings leaching hard after enrichment, and that the enrichment here is thin and spotty on that account. This is controversial matter and is seldom pertinent to the argument. It is much better given merely as a suggestion. The important thing is the *fact of thin and spotty enrichment.*

To amplify these considerations: the geologist without commercial training on undertaking commercial work is likely to do his work and to write his report as though it were, not an argument, but a geological exercise. He has a notion as to the "right way" to do geology and write a report. He has scientific ideals which lead him to handle the geology comprehensively. He feels that he must give an outline of geological history, describe the rocks with petrographic detail, and have a heading, "The Origin of the Ores." Were he discussing a town lot for a buyer, he would never dream of explaining its physiography. But in discussing a mine for an owner he is prompted to consider subject after subject of equal remoteness. Furthermore, he not only answers questions which the reader does not ask, but fails to answer questions which are uppermost in the reader's mind. Above all things, if the report concerns a prospect, these questions concern the possibilities for further ore and the cost of testing them out. He allows the reader to search the report through and through without getting adequate answers. Clearly he and the reader are at odds.

Geologists without commercial training are by no means alone in producing reports of this sort. Most reports are of this sort. And the geological maps themselves are no less at fault in this point than the reports. We should particularly expect a map to be concrete, and so it may be in the facts which it presents; but it may be far from concrete in the application of those facts to the discovery of ore. With certain notable exceptions, such as those of the Anaconda Company, the maps made in the usual course of staff mining geology are loaded with answers to questions that were never asked. They carry a miscellaneous aggre-

gate of information which may be loosely classed under the heading "geological." They are like trunks packed for emergencies in general but for no emergency in particular.

They portray, for instance, rock alteration. But what, in terms of ore, does the particular alteration mean? Some experimental mapping must, of course, be tried. But unless this produces a logical basis for the belief that the mapping of alteration will aid in discovery of ore or in some other way, it should not necessarily be accomplished. There is no essential virtue in the production of a photograph in miniature of the mine. In a drift carrying a complicated mixture of andesite and monzonite, the detail shown on paper is not necessarily more useful than the detail shown underground. There is needed a careful consideration of the *purpose,* and no good opportunity should be missed to express the facts which will especially aid in ore-finding. A caricature, making the economic features stand out and subduing all the others, is likely to be far more appropriate than the humdrum conventional map, muffled in non-essential detail. The maps are usually poor. No less than the reports, they are made with but a vague foresight of their application.

This is a serious indictment of mining geology as it is now practiced, and it is intended to be so. There is no more important cause for the lack of financial support than the failure of the geologist to understand the operator's aims. Not only does he look away from the pertinent problems, but, by seeming chiefly interested in non-pertinent problems, he destroys the confidence in his judgment so necessary to the execution of his ideas.

A vivid account of a situation where the technician, in place of fumbling, understood the needs of industry better than industry did itself is given by Dr. Arthur L. Day in his narrative of American optical glass in the war emergency. Dr. Day says:

"A special heavy flint, for example, which was desired by the government, was made in no more than two trials. To properly appreciate just what this progress means, it may perhaps be recalled that in the days of rule-of-thumb glass making, as many as 150 essays were necessary before a glass of predetermined optical constants resulted. This kind of

knowledge applied intelligently, commanded for the laboratory workers the immediate respect and confidence of the workmen, who had hitherto believed these things to be shrouded in impenetrable mystery, and contributed in no small degree to the rapid progress and wholehearted coöperation obtained."[4]

Though mining geology cannot often enjoy such startling success, it must clearly aim for this kind of success. Its reports must carry the reader along to some effectual conclusion and must focus the attention, not only of the reader, but of the writer himself, on those considerations, chiefly empirical, which are concerned with ore discovery. A synopsis in brief form will be an aid in this direction. Often enough the geologist will find that with the removal of all answers to questions that have never been asked, or that have no reason for being asked, and with the removal of presuppositions and prejudices, he has very little left. Obviously, it is that part of the report which extends down to the ground which will be mainly serviceable in mining. The geologist will never be able to make good records or to do good goelogy until he is able to analyze the arguments in his own work, and to know in just what degree they are apriori and in what degree empirical. Any geologist who shows weakness in this respect is open to serious challenge. Usually his work will have little usefulness.

THE DEGREE OF DOUBT.

Another cause of vagueness is the common error among geologists, especially those with unripened judgment, of giving conclusions without stating the *degree of doubt*. The degree of doubt is indeed the stuff from which the whole usefulness of geological work must be made. And it is a matter for the nicest balance of judgment; it can be determined only when all the conflicting forces of prejudice and immaturity are overcome, and expressed only through some degree of literary skill.

Let us examine this matter first in one of its more obvious aspects. A certain prospect, according to a rough measurement

[4] Arthur L. Day: "Optical Glass and its Future as an American Industry," *Journal of the Franklin Institute*, Oct., 1920.

based on our experience, has one chance in ten of yielding important ore.[5] Then, if our plan involves the testing of ten prospects of equal promise, we can be reasonably sure of one success. We shall go further with this prospect, therefore, only if the cost of ten such enterprises would be warranted by the success of one. Accordingly, the decision regarding the next step is dependent on the chance of success in the prospect in question, and a report which in its conclusion fails to designate in some way the quality of this chance is failing to give a basis for judgment.

But we must express the degree of doubt, not only in giving our recommendations as to the next step, but also all through the report, and this means, to put it in other words, that our mental processes must all through be quantitative rather than qualitative. If, neglecting this principle, we say, "The cropping is strongly iron stained," we are taking refuge behind vagueness. For iron stain in the cropping is of no consequence whatever unless we can express it in terms of the iron percentage and in terms of a comparison between this cropping and a cropping known to correspond to a particular grade of sulphides. Obviously, in the long run, judgments based on qualitative geological knowledge are certain to be unsound.

The degree of doubt is important, furthermore, not only from the standpoint of soundness, but also from the standpoint of carrying conviction. Failure to express it suggests failure to know it; the reasoning lacks the very quality that is necessary above all others to make it impressive—the evidence that the subject has been well considered. To the discriminating reader, if it lacks this quality it is as unattractive as a strawberry devoid of flavor.

And emphasis of this matter of the degree of doubt is especially desirable. For geological considerations tend especially to the qualitative. The geologist sees a gossan cropping representing the leached "ashes" or "clinker" made from sulphides by the slow burning of oxidation. Were these sulphides pyrite

[5] An accurate measure of this proportion is only the desirable ideal; it is of course practically impossible.

or chalcopyrite? At what depths will they appear? What is the attitude of the mineral body? What is its width and length? At the north end, where it disappears under soil, how far will it continue? The geologist says he *thinks* it is from pyrite with a little chalcopyrite; that it will make sulphides at 250 feet; that the body is steep; that it is 50 feet wide and 600 long; and that its extension under the soil he cannot estimate.

But we know that while some of these matters are easily determinable, others are difficult; if the geologist fails to qualify and define at every step he takes, we are likely to doubt him altogether. There is copper stain in the cropping. How much? There are a few specks of chalcopyrite still unoxidized, and no pyrite. What is the chance that pyrite has yielded to oxidation more readily than chalcopyrite, and that the chalcopyrite exhibits at the surface a misleading ratio? What is the geologist's actual experience in this respect in other districts and especially in this one?

After all, on the basis of frequency, we may be sure that the general chance that this is a deposit of commercial ore is less than one in many score. On the basis of the evidence present here, are we compelled to consider its chances better than this? Just what are these evidences? How conclusive? Not conclusive at all in the absence of something both specific and compelling, and in that case we can safely reject the argument. For a prejudice founded on vague impressions is only too easy to achieve. We can scarcely have the simplicity and "softness" to give it credence.

But this, of course, does not mean that the geologist is to clear his thinking and writing of all speculation. The reader can be trusted with all his thoughts. Speculation qualified with a clear indication of the degree of doubt is the soul of the report. The more active-minded the writer, the more thoughts and considerations he betrays, the more conviction he carries. We may beware of the geologist with the cold soul, who can think only in terms of what he can see.

Geology is, indeed, no more than speculation; but, to be useful

in mining, it must be speculation producing information in the order of its pertinence and cheapness. It is speculation with its more fantastic parts cut off; with its chief attention fixed on the probabilities defined by empirical evidence. It is speculation clearly betraying the degree of doubt.

COMPLETENESS.

Another source of vagueness, closely allied with those already discussed, is incompleteness. The purpose of completeness is, of course, twofold. First, that the subject may be thoroughly and logically covered, and second, that it may avoid a result arising from obvious omissions—failure to carry conviction.

From the absolute standpoint, it is clear that no work can even remotely approach completeness. A study of a single problem in a single district could be made to touch every facet of human knowledge. And this means that the term completeness must be a relative one. In the Geological Survey, for example, it signifies the accomplishment of a standard form of report proved serviceable. In the sense used in this paper, it signifies the inclusion of all obviously pertinent considerations. Thus, the discussion of a disseminated copper deposit in monzonite that has limestone walls would be incomplete unless it considered possibilities for ores in limestone.

The geological record must deal, therefore, not only with the conditions that are present, but also with those which under the circumstances might conceivably be present and which, nevertheless, are absent. For example, any contact-metamorphic copper deposit may be interesting because of the supposed possibility of disseminated copper mineralization nearby. The report would properly discuss the absence of this mineralization, were it absent. It would explain how this absence is proved; how well the rocks are exposed; where they are covered; and whether or not there is a chance that disseminated material lies hidden by soil.

In numerous instances the prospect, obviously hopeless, may be banished with a gesture, and in this case the geological record

may be made complete with very brief discussion. For in the particular prospect the proved absence of a single necessary feature will release us from further discussion. If, for example, we are looking for big ore-bodies, then large size is essential. And once we establish smallness, we are done, no matter what other aspects there may be.

But when we come to a prospect where there is no such easy means of condemnation, the test of adequacy or of completeness is, indeed, a difficult one. Clearly, we cannot present a complete argument. From the manifold possibilities on what shall we focus our attention? And how shall we know when we are through, first with the geological study and second with the writing of its record?

To come, then, to the test of adequacy. Ore sampling has a method that will fit our case exactly: the samples there are taken in such thoroughness that a second and parallel set will not vary in essential results from the first. And so with the prospect examination—if Wednesday add no new thoughts to Tuesday, we are getting on. Though we focus on it our most ardent attention, the prospect changes in no important aspect. We may come back again in a week and still no new concepts rise to greet us. The examination is carried to the point where no new vital considerations are coming in. We have achieved *stability of opinion.*

This is the test of completeness so far as the individual is concerned. The intrinsic completeness which it produces will, of course, vary with the mental power of the geologist. The ill-trained or unimaginative man using it would, of course, produce but sorry results. But it tells us when we have gone as far as our powers allow.

To make a skillful application of geology to the problems of ore-finding, so long as the proposed exploration has a chance of getting important ore or the prospect still offers possibilities of becoming a mine, we must do this much.

And this much cannot be accomplished hastily. *It takes time to do geological work.*

COÖPERATION.

Still another cause of vagueness, and the last which will be considered in this paper, is concerned with isolation. Isolation is indeed a bad ailment for the geologist. For there is something ridiculous and at the same time sinister in the old prejudice—"My property is my business." Secrecy in a mine occasionally means dishonesty; it usually means ignorance. The self-sufficiency that puts the geologist under ground to be, like the tram mule, a prisoner from the light, condemns him to something close to futility; by keeping his achievements secret, it tends to keep them meager.

And there is a mien of secrecy, not enforced by the company, but assumed by the engineer himself, which needs discussion here. It consists in the rendering of opinions, with either sketchy reasons or no reasons at all. Now, when the engineer possesses a good reputation and a full grasp of his subject, he can discipline his clients to trust him, and he may make this method both dignified and successful. But when the information is only partial, as is usually the case in the prospect examination, the method is to be strongly condemned. For prospect examination has a technique which, now being poor, is likely to improve only through coöperative work. And while secrecy in the use of such a technique at its best serves no purpose except that of guarding information which might aid a competitor, at its worst it has many dangers. It is an invitation on the one hand to bad work and on the other to distrust. It tends to substitute personality for competence and many an impressive fellow has thus hidden behind it. It is a survival of the time when technical skill was a mystery. It tends to keep it a mystery.

The habit of giving opinions without discussion, bad enough for the ripened engineer, is exceedingly bad for the young man. For him it would not go amiss to spend fully half his time getting his arguments into a clear and complete condition. He would do well to publish and to consult at every opportunity.

This squeamishness on the part of mining companies regarding the publication of facts about their mines is a regular old man of the sea on the shoulders of mining geology. A staff geologist who has no desire to publish, who fails to understand the necessity for coöperation and the necessity for sharing his problems with others, is unlikely to do important geological work in a big sense. And, unless there is solid reason for doing otherwise, mining companies will do well to rebuff the secret worker and raise a man's pay if he can write a good article and attract interesting opinions from other geologists pertaining to ore discovery in the mine.

But this coöperation cannot be content with the mere lifting of the ban of secrecy, nor with the mere motions of acquaintance and good fellowship. It must rest on a positive ability for cooperative work. It must, in fact, involve that rare quality, genuine intellectual fairness.

Now, it will, of course, be understood that too much fairness, in one sense, may have the practical effect of weakness, for it may yield conclusions with so little force of belief that they will fail to carry the conviction needed for action. It may often constitute a merely negative or passive quality—a lack of something undesirable. Fairness by itself, then, is not a quality to carry the geologist on its back. But fairness may be made a positive quality. A man may be aggressively fair. He need not be weak; he may even, with his inflexible tolerance, bring others to "beware the fury of the patient man."

In this positive sense fairness is an important motive in ore-hunting. If two observers differ sharply in their opinion on the meaning of a cropping, then, assuredly, the geology is somewhere bad. Geology is no place for harsh differences of opinion and the worst aspect of apex litigation is its encouragement and conspicuous exemplification of such differences of opinion. For it, these differences, incompatible with the fine progress of the profession, become highly profitable in fame and money to the technician. Apex litigation is the enemy of coöperation—and in that sense it is the enemy of geology.

The controversial spirit, indeed, poisons geological thinking. We may beware of the man who, in his intercourse, seeks disagreements rather than agreements; the arguer taking joy in the argument for itself. We may condemn him because he will meet his opponent on any ground of disagreement whatsoever, and, in the noise of battle, forget the conclusion. We may even condemn him because he is sarcastic, or an atheist, or a narrow sectarian, or a paranoiac, and we will be interested in his health, because, of the causes of unfairness, poor digestion is among the worst.

For geological judgment is the work of a poised and delicate machinery. Functioning freely, it will yield true results. Trammeled even slightly with prejudice, it will yield an error, perhaps small in itself, like the falseness of an escapement, but large as it mounts up hour by hour. The whole soundness of a geological judgment will, indeed, rest on a quantity of contributing judgments which must be individually sound. To disturb these with temperamental motives, to gloss them over with geniality or ready words, is to make the total judgment as false as a watch with a bent shaft.

The geologist must, in short, subordinate temperament to logic. He must love ideas for themselves, and if they issue from the minds of others, he must love them no less than his own. We may avoid the man who rides hobbies. We may avoid the man who is always seeking preferment for his own mental offspring, who is always listening to the tones of his own voice.

Cardinal Newman's definition of a gentleman expresses the quality of fairness needed:

> ". . . a foe to violence of opinion or expression; an enemy at the same time of restraint, suspicion, gloom, or resentment; . . . suppresses his own egotism . . . is scrupulous in imputing motives; is never mean or little; never takes unfair advantage and never mistakes personalities or abuse for argument."

Such a man, if there be any such, would be good stuff for geology. And the qualities of such a man need especial encouragement in geology because they are seldom met there and be-

cause they are especially essential there both for straight thinking and for effective coöperation.

QUALITY OF RECORDS.

The record is obviously the chief means by which geological work may become effective in human affairs. And it is obviously an intrinsic part of geological work—so intrinsic, indeed, that we are likely to think of the work and of the record together. Let us therefore devote a few pages specifically to this matter.

The principal varieties of records with which the ore-hunter is likely to be concerned are: first, reports, based on the examination of mines or prospects considered for purchase, and concerned mainly with possibilities for further ore; and, second, reports on going mines for the guidance of exploration.

Between the written record and the spoken word, through which geological information is often transmitted, say, to the mine superintendent, there is a fundamental difference of quality. Both, it is true, are judged on a dual basis, the personality of the speaker and the logic which they carry; but the relative importance of the two factors varies greatly between the two methods of presentation. The spoken word may have its logic wholly dominated by the magnetism of the speaker, and it may carry conviction through that magnetism alone. The written record, on the other hand, though betraying the personality of the speaker, needs, to carry conviction, a far greater ingredient of intrinsic logic. It lacks the living warmth of face to face discussion. It fails, relatively, to create an impulse of good will or hostility at the beginning. Containing mistakes, it is far more likely, therefore, to betray them. A man may speak well and write poorly, and doing so he is subject to suspicion, for his principal reliance may be personality rather than logic. As the geologist, then, is concerned chiefly with logic, we may say that the written record lies closer to his heart.

In a relatively feebler way, however, the written record does itself have a personality, and this personality does, in fact, create

on the part of the reader a predisposition friendly or hostile. It will be realized that the man of business bases decisions in technical matters largely on the apparent character of the technician bringing those matters to his attention, for his principal expertness lies in a faculty of shrewd, quick judgment of men. He will often, therefore, in reading the geologist's reports, listen more attentively to the tone than to the matter. He will have an eager eye for mistakes. Not usually following with nice discrimination the intricacies of a technical argument, he will instantly detect a flaw in what is called "common sense," and no amount of technical skill will in his mind neutralize the bad effect of a "break." Any lack of sincerity, any obvious inaccuracy, though leaving the main argument unaffected, will breed instant distrust. True it is that the man of established reputation can get by with little errors. But the unknown—and the geologists of the coming decade are mostly unknown—will be met with a skepticism amounting to the "will to disbelieve."

The report, then, may betray eloquence, or volubility, or literary skill, and it may carry evidence that the writer's interest is more in writing well than in writing truly. Should John Galsworthy produce a prospect report resembling some of his essays, we could reject it because the main effort had clearly gone into style. We could feel sure that he had but little thought for the virtue of the prospect; we should know that he found it so easy to talk people down that he was content with mere brilliance of effect.

In the hands of a shrewd workman, the report will be made to carry a specific impression of character, and will arouse the expectation of a real idea behind every utterance, no matter how crudely it may be expressed. The writer needs to establish the conviction on the part of his reader, first, that he is sincere; second, that he is fair-minded; and, third, that he is able. No matter what facts appear, nor what inferences, these three conclusions must be accepted in advance of a favorable effect. The facts and the inferences will have little significance without them. Perhaps the geologist will indulge in a careless use of

superlatives. In so doing he is self-condemning. Or perhaps he will unwittingly betray his main interest as pure geology rather than as the use of geology in providing guides to ore; the moment he undertakes to discuss geology for itself, he will prove himself off the subject and will thereafter require high powers of persuasion to make his opinions seem, in the eyes of the experienced reader, to be important.

One of the tests of shrewdness is the sense of humor. The part played by it in geological work is not tangible, nor specific, but this does not mean that it is not important. For a sense of humor, well rounded, is an excellent business asset. It enables the geologist to see himself in others' eyes. It leads him away from extremes of opinion and toward habits of deliberation. Possessing it, he will seldom yield to over-exuberance. Lacking it, he may fall a prey to the experienced man of the world and must bestir himself to gain experience that will make him safe despite his natural handicap.

In the report, deficiencies in the sense of humor quickly manifest themselves. And because the business man may instinctively take them as the badge of immaturity or of incompleteness, they constitute one of the little things which give to a report a "bad personality" and which detract from its ability to carry conviction. Some examples will illustrate the meaning:

"The East Vein is a quartz vein."

". . . low rolling country at an elevation of 6500 feet."

". . . four small but well cared for buildings."

"The property is well explored, well located, low-grade and provided with a spring."

These are, it is true, capable of no misunderstanding. But they prove that the writer, however accurate, is insensible to a certain aspect of the situation; so grimly does he grind out the facts that he forgets his audience; so hard is he at work that he loses his way. He needs deftness and proves himself a bungler. He fails to test his report from the standpoint of one seeking to find it ridiculous. He forgets what is in another's mind. In one direction he leaves the report vulnerable.

The able chronicle is, not a net-full of facts, but a table-full, nicely selected and set out; not a photograph, but a picture. The writer, if he become too invariably serious, will in part miss the critical faculty, and will fail to do his best to arrange and to qualify. If, on the other hand, he be nimble-witted, he will test his writings with gaiety and sadness, lightness and heaviness, grimness and laughter. He will leave no aspect unessayed, and will never be so dull as to sit unsuspecting alongside while the reader laughs.

The report, then, must yield a favorable impression of motive and ability. It must, furthermore, tell the story in terms that will be understood, and in terms that will command attention. In other words, it must have not only the quality of obvious soundness, but also the characteristics of clearness, emphasis and interest.

These characteristics will now be further defined. Ordinarily speaking, the report should be so clear and its principal conclusions should be so emphatically and interestingly stated that the whole meaning will force itself upon the reader with little effort on his part. There may come a time in the future when geologists will be so respected that lapses in presentation will be overlooked; but that time is not yet here. Unless the meaning jumps forth from the page and takes firm hold on the reader's thoughts, few will bother to investigate it. We have no reason to hope that our readers will conduct a research in order to uncover our meaning.

A primary requirement, then, for a report is that it feed the reader's appetite. It must answer the questions which he wants answered. It must go straight to those matters of ore-occurrence and ore-position which he can use tomorrow and next week in the direction of his men. In the particular deposit there may, for example, be three ages of faults, one earlier than primary mineralization, the next between primary mineralization and secondary, and the third later than secondary. The report may well concern itself with the questions: What interest has this distinction of age for the reader? How will it affect his

mining operations? And if it will affect them, how is the distinction to be made between faults of one age and those of another?

We must answer the questions that are asked. And if there is important material on which no questions are asked, it is essential that we stimulate their asking. We must feed the appetite which already exists and create an appetite for knowledge which we know to be pertinent. We must never commit the sin of addressing a bored audience. There is a kind of deftness that always feels the quality and motives of the audience. Equipped with it, we will think like geologists, but talk like engineers, lawyers, or mine superintendents.

Failure to do this will often result in the presentation of material without obvious bearing on the argument. Lists of facts regarding the rocks are an example of what is meant, and highly technical arguments of interest only to some other geologist. Reports may sometimes well include such matter, but in such a way as not to pad or obscure the main argument. Often they will carry it best in an appendix, with a clear designation, by title or preliminary statement, that it is given simply for the sake of reference and is intended only for special readers.

In the direction of clearness, a useful thing is a preliminary statement at the beginning of the report indicating exactly where the argument lies. A busy reader is, of course, grateful to be told on exactly what pages he will find the material for which he is looking; to know exactly what pages he should see in order to understand the principal argument, and what pages he should see if he wishes to go into the matter with further regard for technical detail. A list of headings, especially where the headings are carefully worded, is a great help in this respect, and the limitation of the body of the report to the principal argument, and the use of the appendix for other matter, will be of assistance.

It is good practice to experiment with writing a report, making a clear designation of the effect of each fact on the argument and of its interest to the reader. One may even put in paren-

theses statements of the bearing of each fact or conclusion adduced. If geologists would work with this idea, they might like it so well that they would sometimes follow it in writing reports in their final form, producing, perhaps, an awkward style, but an exceedingly appealing and usable result.

In this general connection, the use of sketches and maps is a matter of great importance. Nothing is easier than to group a report about sketches, nor to understand it when it is so grouped. But by words alone the *geographic placing* so essential to clearness is often a difficult matter. It is difficult even for the skilled writer. For the unskilled it is impossible.

Yet the geologist shows a strange prejudice against the use of sketches. Sometimes, perhaps, he shrinks from the incisive quality of a sketch—he prefers the latitude which words allow—but mostly he fails to appreciate his inability to make his thoughts clear. He needs to compare independent reports on the same subject before he will realize that two men can talk of a single prospect as though it were two different prospects.

The advantage of a sketch is vividly suggested by the difficulty one has in locating his house for a stranger by words alone, and the ease with which a diagram makes it clear. This method in prospect descriptions is so useful that we can almost make a rule, "No report without a sketch." Accurate measurement and careful drafting are not always necessary. Any delineation of space relations is better than none so long as it bears an expression of the degree of doubt.

Sometimes the whole report can be made on the sketch. To attempt so to make it is good practice. But usually, of course, the combination of sketch and text is the more advantageous, and the man who is not highly skilled in writing, if he has any shrewdness whatever, will not fail to make use of it.

Another important matter, from the standpoints both of clearness and of emphasis, is the summary. And the summary may be not merely a boiled down essence of the report. It may be and should be a kind of framework on which the report is built. A synopsis containing a brief statement of every argument in

sentence form is an excellent device from which to write. And such a synopsis or summary may even be placed at the beginning of the report, so that the reader may have the broad view of the whole subject before he plunges into details, and so that he may, if he chooses, go no further than the broad view.

The articulateness needed in geology is, then, ability to talk or write in words that will inspire action by making the meaning sharply evident to a special audience. Articulateness in this sense is seldom natural. But it is part of the geologic skill which can be gained by repeated experience. If the reasoning be good, the writing is likely eventually to become good. If the reasoning be good, the main difficulty in the writing is likely to be that initial self-consciousness which afflicts most people when they put pen to paper. And, for this, practice is the principal cure. Any good geologist writing ten reports of ten thousand words each is likely to find himself at last writing with facility and success.

In addition to its function in making geology effective, the report has another and equally important function. It may be made to act as a stimulus for good thinking on the part of the geologist. We could almost say that there is no good geology without a record. Either the mind is too languid or the intricacies of thought are too great to be stimulated to completeness without the cold materialization that comes when the argument is put to paper. And, without a record, there is no communion of ideas between the geologist and his fellows. He stands solitary, with no opposition to whip his thoughts.

On either basis geological work may well have its pertinent matters completely recounted. Now and then geologists will find it well to write two reports, one for themselves and one for their clients. It is bad policy to let ideas escape. If we are to get away from vagueness, whatever its cause, we must make a skillful record; for the record is the best known mechanism for enforcing both definiteness of thought and definiteness of expression.

DIFFICULTIES IN THE CHOICE OF MEN.

These considerations define certain faults in commercial mining geology and certain powers to overcome them. At this moment these powers are but ill represented among geologists. And this condition results partly from the inability of the executive to find competent men.

Competent appliers are, indeed, few in number, and the executive does not know where to turn to get them. He cannot get them from the universities or from the geological surveys, for these, necessarily concerned more with the general principles than with the specific principles needed for exploration, turn out few ore-hunting specialists. The executive is forced, therefore, if he wants a geologist, to create one with no careful search for qualities which seem both vague and unattainable. He sends to a school for a man. Or, with better information of men in his own organization, he addresses thus the shining face of youth:

"You are no longer a surveyor. Put aside your transit and bring out your powerful and accurate imagination. I name you geologist of this mine."

In making this sort of an appointment the executive is usually acting on his knowledge of character and choosing a man who fits well into the organization and who, according to the executive standard, is competent. But the executive standard is not sufficient. And the man selected, though likely to have certain executive abilities, will only by accident have geological abilities to match.

But if there is difficulty in selecting the applier, there will be still greater difficulty in selecting the inventor. For there the executive standard fails completely. The common confusion by mine operators between scientists and pedants indicates the truth of this assertion. The scientist has qualities so differing from those commonly needed in business—he is so slow of opinion, so insistent on a logical structure, though months are needed for its building—that no convenient business scale exists to measure him by. There is no recognized profession of commercial geo-

logical research with standards of achievement set. There is not even a clearly recognized list of problems on which he might advantageously work. For the present his wise selection will be largely accidental.

Indeed, the difficulties in the choice of men to act either as appliers or as inventors are certain to be important. Any assumptions of ability based on a hasty appraisal, or on a purely executive appraisal, are sure to lead to mistakes; for the geologist may not be judged to be sound unless he can prove that he is so by *geological* as well as by *executive* standards. And, sadly enough, there is no machinery of selection which combines the two.

This difficulty in the finding of competent men is, then, a serious condition in ore-hunting geology. And there is another serious condition consisting in the removal from the top (by "decantation") of men who have attained success. For should there appear an able man, say, for staff work, there will be real difficulty in keeping him to it. No able man will be long content with the routine, cramped authority, and small pay that go with the usual staff job. He will quit to take something else. He is convinced, and rightly convinced, that the company, though unwittingly, is only playing with geology. And only where the staff job is made really interesting, with opportunity for study in various mines and districts, does the able man devote himself to it.

Or, supposing that the geologist reaches the consulting class. He must be able; being able, he often has an ingredient of business ability; having this ability, he is drawn to use it in other activities. He becomes, say, a mine manager, or mine owner, or editor, and his career as an ore-hunter automatically stops. And, with his going, there is danger that the profession will retain only business incompetents.

We are come, then, to what looks like a fundamental hindrance in the development of ore-hunting geology. For so long as ability is wary at the entrance and adroit at the exit, the personnel will be poor.

CONCLUSION.

In the practice of ore-hunting geology today the defects are many. But we need not therefore despair. For these defects inhere in the critical stage of any applied science—the stage that precedes its public acceptance.

To do our part in correcting these defects, we have chiefly to blow on our hands. It is our task to be the critics—our task to tell good work from poor. Ore-hunting, we may say, needs money for experimentation. But it needs, first, well-made programs. It needs, within its personnel, a craving for experiment.

And the profession of ore-bunting needs able men, inventors and appliers, who will deem it, not their plaything, but their vocation. Such men need not shun it for lack of zest; for it has the lure both of the game trail and of the research laboratory. Nor for lack of financial importance; for it promises to halve the cost of testing prospects. Nor for lack of outlook; for it belongs to the career of business-technician, already proved honorable and satisfying, and promising, in the shadows of the future, to produce the masters of industry.

At this present time, with the swift march of rationality, the critical stage passes quickly. A dozen years and apathy may yield to interest and interest to fevered action; the very fashion of our thoughts may alter; good men may come swarming. For this change we may hope. In it we may play a part.

Easy to say and difficult to accomplish! But there are favoring circumstances.

788 Mills Building,
San Francisco, Cal.

RECENT WORK ON ARCHÆAN SULPHIDE ORES IN FENNO-SCANDIA.[1]

PER GEIJER.[2]

Introduction.—The Swedish Archæan contains a considerable number of sulphide ore deposits which are mostly of rather insignificant size, but includes the Falun mine, for centuries the world's leading copper producer and still an important pyrite mine, and also the zinc deposits of Åmmeberg. Recent studies on Falun and some other districts by the author, and, somewhat earlier, by Dr. P. Eskola on the analogous Orijärvi district in southwestern Finland have yielded results that may perhaps deserve a brief review in this journal, particularly as these deposits represent a genetic type that previously has not been clearly understood.[3]

The sulphide deposits in the Archæan of central Sweden occur in the leptite formation, which also harbors the numerous iron ore deposits of this region. Referring for more details to a review published a few years ago in a paper dealing with some of the iron ore types,[4] I will here repeat only the fundamental features of the general geology of the ore-bearing country.

General Geologic Features.—The leptite formation is of supra-

[1] The name Fenno-Scandia has been proposed by Prof. W. Ramsay, of Helsingfors, for the geologically well defined region comprising the Scandinavian peninsula and Finland, and is being increasingly used by the geologists in these countries.

[2] Geologist, Geological Survey of Sweden, Stockholm.

[3] Dr. Eskola's report, "Petrology of the Orijärvi region," and a shorter paper discussing the relations between chemical and mineralogical composition of the metamorphic rocks at Orijärvi (in Swedish) are published as Bull. 40 and 44, respectively, of the Geol. Survey of Finland. The author's report on the geology and ore deposits of the Falun district is published in Swedish (with a summary in German) as Series C, no. 275, of the Geol. Survey of Sweden.

[4] ECON. GEOL., vol. X., p. 299, 1915.

crustal origin, *i.e.*, consists of rocks formed at the surface. The leptites, its chief components, are very fine-grained gneisses, generally of a granitic composition. Where the formation is less metamorphosed, the grain is finer and the rocks are typical "hälleflintas." Despite the strong metamorphism, volcanic rocks, both lavas and tuffs, can often be identified among the leptites. The remainder is probably also made up of volcanics and their detritus. Femic rocks of the same kinds of origin also occur, but are more subordinate. Limestones and quartzbanded iron ores (also other types) are not uncommon, but mica schists chemically corresponding to shales are rare. The leptite formation has no substratum of older rocks. It rests on younger granite masses. The older ones among these granites, mostly more or less gneissic, appear to have mainly risen along the anticlinal axes in the folded leptite formation, while the younger massifs show cross-cutting boundaries, shatter-zones, and usually the contact relations interpreted as due to magmatic stoping.[5] Exactly the same conditions, both in the leptite formation and in the granites, are found in the Archæan of southwestern Finland, where Orijärvi is situated.

The first detailed geological examination of one of the sulphide deposits in question was Törnebohm's work at Falun, the results of which were published in 1893.[6] Törnebohm found that the ore deposits were associated with a quartzose rock, containing cordierite and an orthorhombic amphibole (anthophyllite). He regarded this ore-bearing quartzite as the result of an alteration of the leptite, caused by diorite eruptions. This view was rather remarkable for that time, although Törnebohm apparently regarded the alteration as a rather "shallow" process, in accordance with his idea not only of the leptite formation but also of the granites. Later, it was pointed out by several authors[7] that many sulphide deposits in limestones or dolomites

[5] Compare a paper by the author "On the Intrusion Mechanism of the Archæan Granites of Central Sweden" (*Bull. Geol. Inst. Upsala*, vol. 15, p. 47).

[6] "Falu gruvas geologi" (*Geol. Fören. i Stockholm Förh.*, vol. 15, p. 609).

[7] K. Beck, "Lehre von der Erzlagerstätten," 1901, and A. Bergeat in Stelzner and Bergeat, "Die Erzlagerstätten," 1904–1906.

of the leptite formation, as the argentiferous galena and zinc ores of Sala, are analogous to contact deposits. Further, H. Johansson showed[8] that the association of sulphides with siliceous rocks high in alumina, ferrous iron and magnesia, as at Falun, is a widespread phenomenon in the leptite formation.[9]

The Orijärvi District.—Eskola's recent work in the Orijärvi district in southwestern Finland gave the following results: Around one of the numerous batholiths of gneissic oligoclase granite[10] that invade the leptite formation, the latter has suffered intense metamorphism. This metamorphism has been of a metasomatic nature, and its products are characterized above all by the development of cordierite and anthophyllite. Feldspar-quartz rocks with these two new-formed minerals probably represent a less intense metamorphism of the leptite, while the combination quartz, cordierite, anthophyllite, or the two last-mentioned minerals with only small amounts of others indicate a more complete replacement. Where there are amphibolites within the metamorphic aureole, their hornblende has been changed to cummingtonite [monoclinic amphibole (Mg, Fe) SiO_3], but the plagioclase is intact. Limestones are changed to skarn consisting of tremolite or andradite. The porphyritic marginal phase of the granite is locally metamorphosed in the same way as the leptite. In the cordierite-anthophyllite-quartzite there are chalcopyrite deposits, the sulphide apparently having been formed contemporaneously with its gangue as a metasomatic product. In the tremolite skarn, there is galena and sphalerite. At one mine, free gold occurs, accompanied by lillianite (a sulphantimonide of lead and bismuth). Particularly noteworthy are the facts that the replacement of leptite by cordierite-anthophyllite-quartzite can be proved beyond doubt, and that the room relations and

[8] *Geol. Fören. Förh.*, vol. 29, 1907, p. 157.

[9] The zinc deposits of Åmmeberg have been described by H. Johansson (*Geol. Fören. i Stockholm Förh.*, vol. 32: 2, 1910, p. 1051, and as guide for the 11th internat. geological congress). As the author has only a very slight acquaintance with them, and it is doubtful whether they are genetically analogous to those of Falun and Orijärvi, they are not considered in this paper.

[10] American petrologists would probably prefer to call this rock a granodiorite.

the metasomatic alteration of the granite margin point to the granite as the mother rock of the ores. However, Eskola has also found similar metamorphic rocks at great distances from any known granite.

The Falun District.—In the immediate neighborhood of Falun[11] in Sweden, the leptite formation is intruded by two great bodies of granitic rocks. One of these rocks is a granite gneiss with a metamorphic (grano-blastic) texture. This igneous body is a complex one, its dominant rock having the composition of a granite with predominant sodic feldspar. The other rock has suffered less textural rearrangements and may be called a gneissic granite. Chemically, it is characterized by its dominant oligoclase, and is very closely similar to the oligoclase granite of Orijärvi. Both differ from the Falun granite gneiss by their somewhat more calcic plagioclase.

Near a projecting point on the granite gneiss area, but about 2 or 2.5 kilometers from the oligoclase granite, the leptites grade into a cordierite-bearing mica schist, which in turn, without any sharp boundaries passes into the cordierite-anthophyllite-quartzite of the ore-bearing area. The ores at Falun are classed as "hard ores" and "soft ores." The "hard ores" are phases of the quartzite which contain chalcopyrite (and other sulphides) and thus constitute a copper ore. Törnebohm found that the ore minerals must have been formed contemporaneously with the quartzite. As already mentioned, the same relations have been found by Eskola at Orijärvi. Associated with the Falun hard ores are gold ore bodies, in which the free gold is accompanied by a bismuth-lead-selenium mineral, weibullite (compare lillianite at Orijärvi). The "soft ores" are pyrite bodies with some chalcopyrite, sphalerite and galena. These pyrite-masses are generally separated from the quartzite by a boundary "sköl," a mass of biotite or chlorite and talc. (Other "sköls" at Falun appear to be replacement veins of cordierite and anthophyllite.) Considerable parts of the pyrite stocks contain numerous lime-

[11] The author's work at Falun may be regarded as a revision and an enlargement of Törnebohm's detailed survey.

stone fragments, and show the relations typical of replacement deposits in limestone. A little tremolite and actinolite skarn accompanies the sulphides in these "soft ores." Other parts of the pyrite bodies do not contain any limestone fragments, nor any lime silicates, but quartz and a cummingtonitic amphibole. They cannot have replaced limestone, but probably leptite.

The ore-bearing rocks are cut by a number of igneous dikes, consisting of a somewhat recrystallized oligoclase granite porphyry (the felsite of Törnebohm), flanked by amphibolites ("trap"). There are also independent amphibolite dikes. In their original character, these "mixed dikes" were apparently entirely analogous to those, for instance, that accompany the granite of the Kristiania region in Norway, and are closely connected with contact deposits of sulphides.[12] In the outer zones of the amphibolite bodies, or sometimes throughout them, the amphibole is cummingtonite, otherwise an ordinary green hornblende. One of the porphyry dikes is faulted by a "sköl," in this case consisting almost excusively of anthophyllite, and probably a replacement vein. Next to it, the dike rock is altered to a cordierite-anthophyllite-quartzite of the usual type, only the quartz phenocrysts of the porphyry remaining as proofs of the original character. The author's interpretation of this fact, and of the cummingtonite of the amphibolites, is that the metasomatic action continued also after the intrusion of the dikes. It cannot, however, have been entirely later, or the dikes should have been completely replaced.[13] A connection between the mixed dikes and the ore deposits is also suggested by the fact that the dikes are exclusively found within the ore-bearing area or its immediate neighborhood. Therefore, it is highly probable that the dike rocks and the ore-forming solutions came from one source. It is known that dikes of this character are closely connected with granites. At Falun, the chemical composition points to the gneissic oligoclase granite as the prob-

[12] Compare V. M. Goldschmidt, "Die Kontaktmetamorphose im Kristianiagebiet."

[13] There is a certain analogy between this relation and the garnetization of dikes at their intersection with faults, which has been studied by Dr. Knopf in the Yerington district, Nevada (U. S. Geol. Survey, P. P. 114).

able mother rock of the dikes, and therefore also of the ores. The position of the ore-bearing area near the granite gneiss might suggest a genetic relation to the latter, but is more probably due to structural causes.

Other Districts in Sweden.—In connection with the work at Falun, a survey was made of a great number of other sulphide deposits in central Sweden, including Garpenberg, Ryllshyttan, Väster-Silvberg, Saxberget (Rävåla), Kallmora, Yxsjö, and many others. In this way, a somewhat clearer picture than before was obtained of the geological relations of the sulphide ores of Central Sweden.[14] These ores may be divided into two chemical-mineralogical groups, one characterized by a lime-magnesia-iron-silicate gangue and occurring in association with limestone and dolomite, and the other by siliceous rocks, high in alumina, magnesia and ferrous iron. The former are clearly the products of a metasomatic replacement of carbonate rocks. Like the skarn iron ores of the same region, their geological relations and paragenesis are those of contact deposits. The gangue minerals (skarn) are pyroxenes (diopside or hedenbergite), amphiboles (mostly tremolite or actinolite), lime-iron-garnet (andradite), chondrodite, fluorite. The sulphides are chalcopyrite, pyrite, sphalerite, galena, pyrrhotite, arsenopyrite, molybdenite. One deposit (Yxsjö) also contains rather much scheelite. Magnetite also occurs, but the relations between the sulphides and the skarn iron ores are not yet clearly proved. The siliceous sulphide ores are often found in an intimate connection with such of the former group, as at Falun (and also at Orijärvi). It is apparent that the replacement of leptitic rocks has resulted in siliceous ores, cordierite-anthophyllite-quartzite, etc., while the interstratified limestones have been replaced by sulphides with skarn minerals. The general character of the siliceous ores and associated rocks have everywhere been found to be essentially the same as at Falun and Orijärvi. The ore mineral is generally chalcopyrite, but also pyrite, sphalerite and galena may occur in

[14] As mentioned above, Ammeberg and certain other ore fields are not considered here.

commercial quantities. The ore-bearing rock is never sharply defined against the surrounding leptites. The transitional phase is often a quartzy mica schist, with cordierite or andalusite. The chief components of the ore-bearing rocks are quartz, cordierite, anthophyllite, andalusite, iron-alumina garnet (almandite,) biotite. Anthophyllite and andalusite are as a rule not found together, but otherwise these minerals are combined in various ways. Also gahnite (zinc spinel) and staurolite sometimes appear as important constituents. Cordierite, andalusite, garnet and staurolite are mostly developed as big poikilitical grains, enclosing quartz, while the anthophyllite appears as beautiful stellate aggregates. The grain is coarse, sizes up to several inches being nothing exceptional. The quartz grains, however, invariably are much smaller.

Although the chemical composition of these rocks is often that of a shale, the geological relations very clearly indicate their metasomatic origin (compare above description of Orijärvi and Falun).

Discussion of Origin.—While the sulphide ore deposits in limestone exactly correspond to the well-defined group of the contact deposits, those accompanied by siliceous rocks have no counterpart in younger geological systems. A review of a number of important monographs on various contact-metamorphic deposits has failed to reveal anything fully corresponding to this type. Where the limestones carry ore deposits identical to our skarn sulphide ores, the metamorphism of quartz-feldspar rocks has resulted in the development of quartz, sericite and pyrite. The only thing that hints at something corresponding to our ore-bearing "quartzites" with alumina silicates is the occurrence of an andalusite-bearing rock in the San Francisco district, Utah. According to Butler,[15] this rock is a metamorphosed lava rock, probably a quartz-latite, and now consists of 26 per cent. andalusite, 56 per cent. quartz, and sericite. A certain analogy may

[15] U. S. Geol. Survey, P. P. 80.

also be traced in the occurrence of anthophyllite with galena in the Cœur d'Alene[16] and Kootenay[17] districts.

The metamorphism of the leptite formation was undoubtedly caused by the older granites. Both at Orijärvi and at Falun the evidence points to a certain granite as the mother rock of the ores. In other districts, no such connection can be proved, but general considerations show that other intrusions cannot have had this effect, the hypabyssic intrusives among the leptites being too insignificant, and the younger granite group decidedly younger than the ore deposits. Thus the sulphide deposits in question, both those with skarn in limestone, and the siliceous ones, must be interpreted as products of igneous metamorphism under abyssal conditions—in the strips of leptite formation engulfed among the granitic magma masses. This origin explains several remarkable features of the ores. One is the distance from any possible mother rock, which at least horizontally in most cases stretches several kilometers. That such relations must be expected at deposits formed at great depths has been realized by several authors.[18] Observations by F. E. Wright and Ch. W. Wright in the Ketchikan and Wrangell districts, Alaska,[19] show the increase in distance with increase in depth. Another region, where this is illustrated, is Nautanen in Swedish Lappland (compare below). Probably, the physico-chemical conditions determined by depth and stress have also determined the development of the characteristic gangue minerals of our siliceous ores. It is true that these minerals are common as recrystallization products in hornfelses formed at moderate depths and under static conditions, but their development through replacement processes in feldspar-bearing rocks is apparently not possible under these conditions. The absence of veins is probably also due to the same causes.

Similar Deposits Elsewhere.—Among deposits in Europe out-

[16] F. L. Ransome and F. C. Calkins, U. S. Geol. Survey, P. P. 62.

[17] S. J. Schofield, Geol. Survey of Canada, Summ. Rep. 1911, p. 158, and Mémoir 76.

[18] Compare W. Lindgren, "Mineral Deposits," 2d ed., pp. 655 and 750.

[19] U. S. Geol. Survey, Bull. 347.

side Fenno-Scandia, that of Bodenmais in Bavaria seems to be very nearly related to the siliceous Falun-Orijärvi type. It is generally cited as an example of injected sulphide ores. The similarity to Falun has caused several writers to class the latter deposit in the same group. This classification, however, is now known to be wrong as far as Falun is concerned, and the question may be raised whether the geology of the ore bodies of Bodenmais cannot be interpreted as due to such processes as are now known to have been in operation at Falun and Orijärvi. Also the great Broken Hill lode in New South Wales apparently exhibits features that point to a certain similarity in origin to the Falun-Orijärvi type. In North America, deposits of this siliceous type seem to be lacking. The paragenesis cordierite, orthorhombic amphibole, and garnet, was observed by Adams and Barlow[20] in Harcourt township, Ontario. No sulphide minerals are reported, however.

Deposits of deep-seated origin accompanied by skarn silicates are more common. The pyrrhotite ores of Ducktown are a well-known example.

The Nautanen Type.—Finally, mention may be made of a different copper ore type, that of the Nautanen district, east of Gellivare, in Swedish Lappland. These ore bodies are not of any economic importance—they are rather small and of a very low grade, and mining in the district has proved a failure—but they represent a new genetical type: chalcopyrite with scapolite and tourmaline. They also illustrate the occurrence of high-temperature replacement deposits at a long distance from their igneous mother rock.

In the Nautanen district,[21] a formation of leptitic rocks with subordinate mica schists and quartzites (also the two latter rocks certainly of a sedimentary origin) is intruded by great granite batholiths. The whole complex is pre-Cambrian, and probably to be classed as Archæan. The granite is accompanied by

[20] "Geology of the Haliburton and Bancroft Areas," Geol. Survey, Canada, Mem. no. 6.

[21] The district was surveyed by the author in 1916. The report is published in Swedish as Series C, no. 283, of the Geol. Survey of Sweden.

numerous pegmatites, intruded in the surrounding leptites. In the outer part of this intrusion zone, the pegmatites are rich in tourmaline. The ore deposits lie at several kilometers' distance from any known granite, and generally not even a pegmatite dike is observed within the ore fields. Various ore types occur close together. In highly scapolitized leptite with some tourmaline, chalcopyrite and magnetite are developed. Some of the best ore bodies were replacement veins of various silicates (garnet, hornblende, biotite) with magnetite and chalcopyrite. Further, there are zones of schistose leptite, impregnated with garnet, chalcopyrite, magnetite, and tourmaline; replacement bodies of quartz, magnetite, chalcopyrite, pyrite and tourmaline, quartz veins with chalcopyrite and accompanied by an intense tourmalinization of the wall rocks, quartz veins with bornite, veins of hornblende and apatite with magnetite and sulphides, impregnations of apatite, etc. Zeolites, notably stilbite, have often been the last minerals to form. Particularly interesting is one occurrence of quartz veins with calcite, chalcocite, specular hematite, biotite, stilbite and some free gold and accompanied by the development of scapolite and tourmaline in the immediate wall rock.

The observations at Nautanen have established a connection between the great granite masses of northeastern Lappland and the regional scapolitization of the older, supracrustal rocks. This scapolitization has been studied by Sundius[22] in the country south and west of Kiruna. In part of this district, the metamorphism has taken place at comparatively moderate depths, the finer textures of the igneous rocks are preserved, and the scapolite has formed mainly along joints, in the interstices between the pillows of ellipsoidal basalts, and similar places. In another part, however, the supracrustal rocks are recrystallized to leptites and amphibolites, and the scapolitization has been contemporaneous with the recrystallization. Scapolitization is known from points that lie many kilometers from any exposed granite.

DJURSHOLM, SWEDEN.

[22] "Beitr. z. Geologie d. südl. Teils d. Kirunagebietes." Uppsala, 1915 (in the series "Scientific and practical reseach in Lappland, arranged by the Luossavaara-Kiirunavaara Company").

ORIGIN AND COMPOSITION OF CERTAIN OIL SHALES.[1]

REINHARDT THIESSEN.

This paper comprises part of a preliminary report on the microscopical study of oil shales undertaken in cooperation with oil-shale retorting experiments carried on by the Bureau of Mines at Salt Lake City, Utah, and with the State Geological Survey of Kentucky.

A shale is generally defined as a rock formed by the consolidation of clay, mud or silt, having a finely stratified, laminated or fissile structure. When such a rock contains organic matter it is termed carbonaceous or black shale; when the matter is of a bituminous nature it is called bituminous shale, and when rich in bituminous substances, yielding oil and gas on distillation, it is called oil shale.

There are many deposits of shale now known that contain more or less organic matter and which when distilled yield gas, oil, and tar. In the last few years, some of these have received considerable publicity, particularly those of Colorado, Utah, and Wyoming; while others, like those of the Devonian of Illinois, Indiana, Ohio, Kentucky, and adjoining states, covering a vastly larger territory, have received but little consideration.

No attempt has as yet been made to classify them either from the standpoint of origin or composition. The same shale may go under different names by different authors or in different state irrespective of similarity or dissimilarity of structure, composition or origin.

The Chocolate Shale of the Devonian of Illinois has formed the basis of this study. The New Albany Black Shales of Indi-

[1] Published by permission of Director, U. S. Bureau of Mines.

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ana, the Ohio Shales of Ohio and Kentucky, the Chattannoga Shales of Kentucky and Tennessee, were also studied and closely compared. Shales of other geological formations and from other states and countries were also compared.

PREVIOUS INVESTIGATIONS.

Up to the present time no comprehensive account of the composition, structure and origin of any shale is available; but little work appears to have been done in this direction.

The spore matter in these shales was first discovered by Dr. H. A. Johnson and B. W. Thomas[2] of the water supply commission of Chicago. In 1865 to 1867, while constructing the tunnel for the purpose of supplying Chicago with water from Lake Michigan, they discovered yellow amber-colored flat disc-like bodies, varying from $\frac{1}{85}$ to $\frac{1}{250}$ of an inch in diameter, in the bowlder clays through which the excavation was made. On completion of the tunnel large numbers of the same discs were frequently observed in the precipitate of the city water supply. In 1881 when examining bowlder clays collected from the high cliffs on the shore of Lake Michigan, twenty miles north of the city, the same disk-like bodies were discovered. They found them both free in the clay and in fragments and bowlders of shale in the clay. They were later found in the bowlder clays in many localities in and around Chicago, and were soon traced to their origin in the shales of the Devonian deposits of Illinois and other states.

Dawson,[3] learning of this discovery, found them also (1871) in the Devonian shale at Kettle Point, Lake Huron. He describes the shale as being studded with disclike bodies, scarcely more than one hundredth of an inch in diameter. He believed them to be spore-cases and proposed the name Sporangites Huronensis for them, but later,[4] believing that they were sporo-

[2] Johnson, H. A., and Thomas, B. W., "Microscopic Organisms in the Bowlder Clays of Chicago and Vicinity," *Bull. Chicago Academy of Science,* Vol. 1, No. 4, 1884, pp. 35–40.

[3] J. W. Dawson, "On Spore-cases in Coals," *Am. Jour. Science,* Vol. 1, 3d series, pp. 256–263, 1871.

[4] J. W. Dawson, "The Geological History of Plants," 1896.

carps of an ancient Salvinia renamed them Protosalvinia Huronensis. When sections of the rock were made, he found its substance filled with these bodies. They appeared yellow amber in color and showed but little structure, except that the walls could be distinguished from the internal cavity. Dawson, it appears, made no discrimination between a number of different spores.

Edward Orton,[5] of the Geological Survey of Ohio, during the same period found them in the bituminous shales at that time called the Huron shales of Ohio, and ascribes the bituminous character of the shale to these spores. After naming various fossils found in the shale, such as Dadoxylon and Calamites, he says that the former are of small account when compared with certain microscopic fossils that are with little doubt of vegetable origin, and which are accumulated in large numbers throughout the black beds of the entire shale formation, composing sometimes a noticeable percentage of the substance of the rock, and apparently giving origin to an important extent, to the bituminous character of the bed. No characters beyond the spores and a few fossil plant fragments were given.

EXPERIMENTAL STUDY.

The oil-bearing shales from the Devonian of Illinois, Indiana and Kentucky are quite similar and for a general description, may be treated alike. What is said of the one is true of the other with but few exceptions. The Chocolate shale of Illinois is taken as the type. The macroscopic appearance of the rocks has been described so often that it is not necessary to repeat it now. The shale is in the main composed of three distinct components: clay, pyrites and organic matter. These three constituents vary in proportion from place to place and from layer to layer, sometimes in close succession. The clay may be said to form the base in which the other components are embedded, and generally constitutes the largest proportion.

[5] Orton, Edward, "A Source of the Bituminous Matter of the Black Shales of Ohio," *Proc. Amer. Assoc. Adv. Science,* Vol. 31, pt. 2, 1882, pp. 373–384. Geol. Survey of Ohio, First Ann, Rep., 1890, pp. 32–33. Geol. Rep. of Ohio, Vol. VII, 1893, p. 26.

The organic matter may be burned out readily at a relatively low temperature without much change to the nature of the mineral matter. The mineral matter is then in a more favorable condition for study. In some samples the remaining mineral matter forms a hard and compact mass, while in others it is delicate and friable, easily crumbling between the fingers. Between these two extremes all intergradations may be found. The remaining mineral matter is of the nature of a clay intermixed with fine pyrite granules. The main bulk of the clay consists of fine grains, as fine as known in any clay; but intermixed with this is always a varying percentage of larger grains of a crystalline nature easily visible under the microscope at magnifications of 200 to 1,000 diameters. The amount of this coarse-grained matter varies considerably in different sections from different localities or in different samples. In thin sections of the shale the fine matter cannot ordinarily be distinguished from the organic matter, while the larger grains are easily distinguished at a magnification of 1,000 diameters, or even at 200 diameters.

The mineral matter on the other hand may be removed largely by means of a mixture of hydrofluoric, nitric and hydrochloric acids, leaving a brown, soft, light matter. In some samples, the remaining organic matter forms a quite compact but highly fissile mass, while in others it forms a very delicate structure disrupting into an ooze-like material at the slightest agitation of the acids. Between these two extremes all intermediate conditions may be observed. The remaining organic matter is in a favorable condition for examination. It may be teased or separated with a pair of needles under a binocular microscope and gotten ready for microscopic examination at higher magnification and used to supplement the study through thin sections.

THE APPEARANCE OF THE SHALE UNDER THE MICROSCOPE.

For microscopic examination, thin sections both perpendicular and parallel to the bedding planes were made. At a low magnification the sections have a yellowish gray appearance, with al-

ternating narrower or broader bands of darker and lighter colors. The darker bands are due to a higher content of organic matter than in the lighter colored bands. These bands shade gradually into each other, with but a few abrupt transitions from one to the other.

Shale at High Magnification.—At a higher magnification, say at 200 diameters, numerous rather large spore-exines embedded in a mass of a light to dark grayish brown color are at once clearly discernible together with numerous opaque pyrite particles already referred to. (Plates IX. and X.) Although the shales have not been examined thoroughly with an aim to distinguish specifically between the spores, three types are distinguishable. One, a large thin-walled spore, contributes a fairly large portion of the three. It is approximately .85 mm. in diameter, thin-walled and shows a tetrasporic cross which marks it as that of a spore of an ancient fern. A slightly larger and thicker walled spore-exine probably contributes the largest number, being particularly prominent in the Indiana and Kentucky shales. (Plates IX. *b*, X. *a*.) It also bears tetrasporic marks and occasionally shows appendages that probably represent air sacks or wings. It is often peculiarly folded, which lends it easily recognizable characteristics. The distinction between these two spores is not always very sharp. Undoubtedly, these are the spores described and figured by the earlier investigators, and called sporangities Huronesis by Dawson. The illustrations given by Johnson and Thomas[6] tally precisely with their appearance. According to their descriptions they are dealing with at least two kinds of spores. The most conspicuous, but which, on the whole contributes the smaller part of the spore matter of the three kinds, is one of a smaller diameter but with relatively thick walls. It is easily distinguished from any other spore, forming an oval in cross section. Attention was first called to this spore by Mr. Culver of the Illinois State Geological

[6] H. A. Johnson and B. W. Thomas, "Microscopic Organisms in the Bowlder Clay of Chicago and Vicinity," *Bull. Chicago Academy of Science*, Vol. 1, No. 4, 1884, pp. 35–40.

Survey. No mention of spores of this description was made by either Johnson and Thomas or Dawson.

The number of these spores and the relative proportion vary considerably from place to place in the same section, and on the whole in sections from different depths of the deposit and from different localities in the deposit. Anyone of these types may be wanting altogether. In some layers they appear to form the largest part of the shale; in others there are but a few. No section was found to be without any. On account of the variability, it is impossible to estimate what proportion of the shale these spore-exines form, but it is safe to say that they form a large part of the organic matter. While some of the spores are clearly distinguishable from the rest of the matter of the shale through their distinct color and outline, the majority are not so sharply demarked. A large number, in fact, are distinguished with great difficulty from the embedding matter and other organic constituents that may be present. This is due to a partial disintegration and change in appearance of the spore-walls.

Embedding Matter at High Magnification.—When a section is examined at a high magnification, at 1,000 diameters or over, the organic matter lying between the larger spores is resolved mainly into three kinds of constituents: (1) fragments of the larger spores in all stages of comminution; (2) relatively very small thin-walled spores, and (3) darker colored organic matter.

The fragments of the larger spores are of a roughly flattened shape, being bent over and under and including grains of mineral matter in their interior present a very ragged and distorted appearance. The small thin-walled spores appear as thin discs, lying horizontally in the bedding planes, but in cross section they appear much distorted and crinkled due to their being bent over and under the larger particles of mineral matter and their intimate association with the clay (Pl. IX. *c*). Most of this spore matter is in a very poor state of preservation and is identified with some difficulty. All the spore matter, whether as whole spores, in fragments or disintegrated, has a light yellow color similar to that of the larger spores. The third constituent of the

organic matter is of a dark brown color and consists of globular to flat fragments, usually of irregular shape and varying in size from minute particles to those easily visible at a magnification of 200 diameters. Much of this matter consists of parts of cuticular matter, such as fragments of leaf cuticles. The origin of the remainder of the darker colored substance cannot be determined further than to say that it is of organic origin and apparently of plant degradation matter. Only relatively little of it is in the form of globules or ovals, and which might be derived from resinous matters. Some layers contain no other organic matter than the third kind described above. The proportion of these three constituents varies considerably in different layers of the same section and also in general in different sections from the same sample and from different depths and from different localities. The one or the other may form the bulk of the organic matter.

The clay is intimately associated with the organic matter and only the coarser particles are discernible under the microscope; the finely divided clay is not ordinarily distinguishable from the organic matter. In examining a section under the microscope, the organic matter appears to form by far the larger part, when in reality it forms only about 10–40 per cent.

Pyrite.—Small globules of pyrite are quite uniformly distributed through the shale. The particles are similar to those found in the coals, but are more uniformly distributed, much more numerous, and on the whole smaller in size and more compact than those in the coals. They range from a few microns to about 20 microns in diameter. They are mostly spherical, only relatively few are of an irregular or rough contour. Occasionally several or a number of globules have coalesced to form irregular masses. The globules are composed of innumerable small cubes as in the coals.

Organic Matter after removal of Mineral Matter.—As already stated, the inorganic matter may be largely removed by means of acids. The remaining organic matter may then be teased apart with needles under a binocular microscope and prepared for examination under the microscope at higher magnifications. The

larger spore-exines may be singled out readily and their form, sculpturing, and size may be studied. In certain well preserved lamellæ where the smaller spores have been well enough preserved, their characters may also be studied. But, generally, the smaller spores are very poorly preserved, so poorly that they could not be identified as spores, were it not for the fortunate occurrence of laminæ with well preserved spores and gradual transition stages from this to such conditions in which they are unrecognizable. Transition stages of this kind lead to the conclusion that in certain sections or in certain layers of sections where no spores are recognizable but where the color is that of the recognizable spores, a certain part of the matter is derived from spores.

Plant degradation matter other than spore-matter may also be distinguished. As has already been noted, some of this is here also recognized as cuticular matter. None or but little resinous matter is present. Most of the organic matter, except the large well preserved spores, has been rendered spongy and porous, while in the untreated sections, this same matter appears firm, non-spongy and more homogeneous. This would indicate that the mineral matter is very intimately associated with the organic matter, or even that the latter is in a semi-petrified state.

The large spore-exines are clearly those of spores commonly met with in the Palezoic deposits. The smaller spore-matter is too greatly changed and as yet it has not been possible to determine to what plant phyla they belong. From what can be learned of them, they are not unlike those of the Ordovician deposits. More study is required to make this point sure.

The Scotch Oil Shale.—A Scotch shale was examined and found to be very similar to the Devonian shales of Illinois, Indiana and Kentucky. (Plate X. *b, c.*) While the same kind of constituents comprise this shale they are present in somewhat different proportions, the pyrite particles in particular occurring in far greater numbers. Many of the pyrite particles have coalesced into larger irregular lumps, also many of them have segregated into broad, irregular sheets, giving the shale a more

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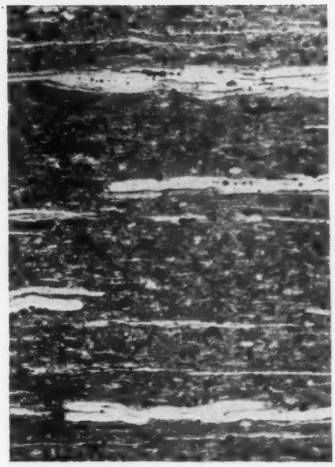

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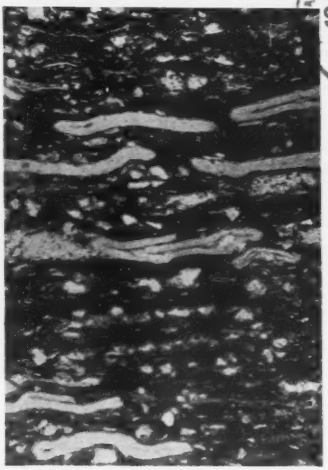

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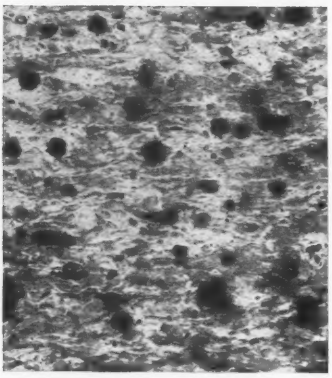


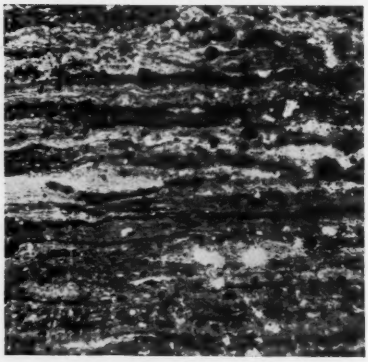
c

a. The white linear patches represent large thin-walled spores. White dots or patches represent clay particles or aggregates. Black dots represent pyrite particles or aggregates. The gray is a ground mass, macerated spore matter, small spores and finely macerated organic matter intimately mixed with fine clay. × 140.

b. New Albany Black Shale, Blocker, Ind. Shows well preserved large spores, also fragmental spore matter. Irregular white spots are clay particles or aggegates of clay particles. The darker shaded areas represent finely macerated organic matter.

c. Illinois Chocolate Shale. Ground mass under high magnification showing fragments of larger spores, smaller spores and other macerated organic matter intimately mixed with clay and pyrite particles as black spots. × 750.

a



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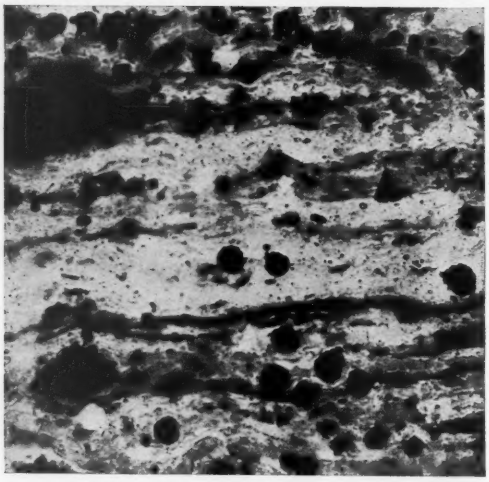

c

a. Devonian Black Shale, Taylor County, Kentucky. Similar to Plate IX. *b*. × 140.

b. Scotch Shale. Lighter irregular areas represent large spores, partly disintegrated and distorted. The grayish bands represent macerated spore matter, smaller spores and other organic degradation matter intimately associated with clay. Pyrite particles, represented in black, are variable in size and irregular in shape. × 140.

c. Scotch Shale. Higher magnification of Plate IX. *b*, showing ground mass, consisting of small spores, fragments of larger spores and other macerated organic matter. Dark spots are pyrite particles or aggregates. × 800.

decided laminated appearance under the microscope. The high content of pyrite gives the shale a dark appearance. The shale also contains a slightly larger number of larger resinous-appearing dark brown bodies of a roughly rounded shape. The larger spores, of which there are several kinds, are of different form and sculpturing and hence are of different species than those of the Illinois shale.

Other Shales Examined.—A sample of the shale from the Pottsville of Kentucky was found to be quite similar to the Devonian shales in composition, but it contains a larger amount of recognizable plant fibers, especially wood fibers, cuticular matter, and charred plant material. Other shales examined, like the Genessee and the Marcellus shales of New York, shales from Elko, Nevada, and shales of the Green River formation at Soldier's Summit, Utah, and from other points, differ so markedly from the Devonian shales of Illinois, Indiana, Ohio and Kentucky, except that all contain pyrite in a similar form, that they require more precise description and cannot be included in this brief paper.

Bituminous Coals, Cannel Coals and Oil Shales Compared.—The anthraxylon in coal, or that part of the coal derived from the larger or smaller fragments of the woody parts of plants, may be said to be embedded in a general debris. This debris consists of all kinds of finely macerated and disintegrated plant matter, together with some mineral matter and is called attritus. It is commonly rich in spore matter. In other words, bituminous coals consist of deposits in which the anthraxylon, or matter derived from wood, forms the predominant part and which contains some attritus and relatively little mineral matter. Cannel coal is a deposit in which the attritus predominates, or is formed entirely of attritus, in which spore matters forms the predominant part, but contains some cellulosic degradation and resinous matter, and has an ash content usually higher than bituminous coals. In the boghead coals the organic matter consists almost entirely of spores. The cannel slate as that from Wrigley, Kentucky, represents a cannel coal in which the min-

eral matter forms the larger part; the organic matter consists largely of spores, some cellulosic degradation and little resinous matter. It forms a rock half way between cannel coal and oil shale. The oil shales of the Devonian of Kentucky have a similar composition, but contain a still larger proportion of mineral matter and less recognizable cellulosic degradation matter and still less resinous matter. The Oil shale of the Devonian of Illinois is similar to those of Kentucky and Indiana, but contains little or no resinous matter.

CONCLUSIONS.

It has been shown conclusively that the oil shales, as far as examined, do not contain oil as such, but that the oils distilled from them are derived from the organic matter contained in them. All the identifiable organic matter consists of plant matter or plant degradation matter. No animal matter has been recognized. The larger part of the organic matter consists of spores, the proportion of spores varying in different shales and in different strata of the same shale. A considerable amount of cuticular matter and some woody degradation matter is also present but little or no resinous matters have been recognized.

From the small amount of work that has been done on the chemical composition of spore-walls and cuticles of living plants it is shown that these are composed largely of the esters of the higher fatty acids, that is oils and waxes.

There is no reason to believe that the spores and cuticles of the Paleozoic time differed from those of recent time. Since the time of their deposition in the shales the compounds constituting the spores and cuticles must have undergone certain changes, due to loss of oxygen, similar to those of the coals in general. In consideration of their original composition they would be expected now to yield paraffins and olefines on distillation. There is still more evidence to be gathered, but the data so far accumu-

lated agree with the theoretical deductions and point to the spores as the main source of the oils.

It is quite obvious that many factors enter into the distillation of the oil shales, and that the more of these factors are known, the easier it will be to control the results and to draw conclusions as to the best method of treatment. There has been some question as to whether the same distillation process can be applied with equally good results to all oil shales, and whether failures in obtaining good results in certain experiments with time tried methods which have been used successfully elsewhere, are due to differences in the composition of the shales or to a misapplication of the methods.

The investigation thus far has shown that while shales from many localities and from different geological horizons are alike and quite similar in origin, composition and physical characteristics, others differ considerably in these respects. The shales from the Devonian of Illinois, Indiana, Ohio and Kentucky, and the Pottsville of Kentucky, for example, are all quite similar in composition and physical characteristics, and it would seem that these could be treated by similar methods with equal success. They are also quite similar to the Scotch shales and it seems justifiable to assume that the old time tried methods of distillation used with the Scotch shale could be used with these groups of shales satisfactorily with but slight modification. This in a measure has been shown to be true.

There are other shales of different geological history which appear to differ considerably from the above in composition, structure and physical characteristics, as for example, the oil shales of the Green River formation of Colorado and Utah, those near Elko, Nevada, and Grand Valley, Colorado.

Not enough work has been done on these shales to make any positive conclusions, but seemingly there is sufficient difference in structure and composition to yield distillation products that differ not only from those of the Devonian shales or Scotch shales, but among themselves. It would also seem that they

required different treatments to obtain the desired results. It is therefore exceedingly desirable to correlate the results of microscopic investigation of structure with the results of distillation experiments in the hope that microscopic examination will become a most valuable aid in the evaluation of an oil shale.

MICROSCOPIC LABORATORY,
CHEMICAL DIVISION,
PITTSBURGH EXPERIMENT STATION,
BUREAU OF MINES.

THE ALMADÉN QUICKSILVER MINE.[1]

COURTENAY DE KALB.

With a note on the ore by F. L. RANSOME.

Almadén, a town of about 10,000 inhabitants, is situated over and around the famous mine which has been so conspicuous in the history of the mineral industry of Spain that the very name *Almadén* is nothing more than Arabic for *the mine*. The population is to a large extent composed of the descendants of the workmen who have for centuries depended upon this mine for a living. With most of them the mining of quicksilver is a traditional occupation. The town is in the western part of the province of Ciudad Real, about 140 miles southwest of Madrid and 7 miles north-northwest from the station of Almadenejos, on the branch of the Madrid-Zaragoza-Alicante railway that runs to Merida and Badajos. The mine buildings are several hundred feet higher than the railway station and all transportation between the two points is by ox-carts, over fairly good roads.

Geology.—Published accounts of the geology of Almadén are in general agreement as to the mode of occurrence of the cinnabar, although they scarcely convey an adequate impression of the possibilities of increasing the known length of the productive zone by additional development along the strike of the ore bodies.

The ore occurs in beds of Silurian quartzite that as a rule strike nearly east and west and stand nearly vertical. On both sides of the ore-bearing quartzite are belts of black slate that is in part bituminous and contains disseminated pyrite. The presence of the pyrite causes them to weather to a reddish soil whereas similar but non-pyritic slates in the region weather

[1] Published by permission of the U. S. Bureau of Foreign and Domestic Commerce, under whose auspices the mine was visited.

grayish brown. The metallized quartzite and its flanking belts of slate are bounded to the north and south by ridges of quartzite that is more resistant to erosion than the rock containing the cinnabar, so that the ore deposits lie in a valley, with, in places, steep, wall-like sides.

Various geologists have referred to a rock called locally "frailesca," which is associated with the ores, and also to a "porphyry" that follows the deposits irregularly. Señor Gonzalo del Rio, the accomplished sub-director of the Almadén mine, to whom I am indebted for many courtesies, assured me that no igneous rock existed in connection with the veins. He also insisted that the "frailesca" was only a breccia, similar in composition to the rocks accompanying the ore. The sample that he took for me proved to be crushed quartzite. The mine foremen showed me the so-called "porphyry" underground, and this has proved to be only a highly crushed and altered rock, evidently derived from quartzite. I collected several specimens from the "frailesca" underground, and these Mr. Ransome finds to be quartzite also. Various engineers familiar with Almadén, with whom I discussed this matter, insisted that the report of the existence of an igneous rock in connection with the Almadén ores was without foundation. Having been particularly interested in determining this point I made special efforts to find such a rock if possible, and the result is that my specimens confirm the opinion of the Spanish engineers. The one rock that bore the strongest resemblance to an igneous intrusive, nearly black in color, and seeming to contain hornblende in a paste, is shown by Mr. Ransome to be a dark-colored quartzite.

The presence of pyrite appears to be characteristic of the quicksilver deposits and of the adjacent slates. It is everywhere associated with the cinnabar in the Almadén mine, both as nodules and finely disseminated. The slates exposed in crosscuts carry pyrite, as small cubes, partly disseminated through the rock and partly along fractures. Southward from Almadén, within 3 miles of the mine, are other depressions, between quartzite ridges, whose surfaces have the same red color noticeable at

Almadén. Whether quicksilver has ever been found in these valleys I could not learn. In any case, the Spanish government has protected its monopoly by reserving the right to any quicksilver deposits discovered within a radius of 15.5 miles (25 kilometers) of the principal shaft of the Almadén mine.

Underground Workings.—As explored and worked, the Almadén mine has a length of 1,000 feet and a depth of 1,150 feet. There are 12 levels. In times past, exploration by shafts was carried on at various points along the line of outcrop for a distance of more than 8 miles. All of these old shafts have collapsed and the position of some of them is no longer known. Most of them are reported to have been sunk between the years 1524 and 1645, during which period the ground was held by the Fuggar family, of Germany.

The Deposits.—There are at Almadén three distinct lodes, which in the central part of the mine are nearly parallel, strike nearly east and west, and stand nearly vertical. The north lode is known as the San Nicholas, the middle lode as the San Francisco, and the south lode as the San Pedro in its western half and the San Diego in its eastern half. On the east the veins are cut off by a fault that practically bounds the explored ground in that direction. Towards the west the north and middle veins curve southward and finally unite, about 985 feet from the fault, in an exceptionally wide ore body. For a distance of 35 feet west from this ore body no ore is found but beyond this interval the deposit reappears with a width of 30 feet, almost in line with the south vein of the central part of the mine. Still farther west this vein divides around a horse 140 feet in length. Comparatively little work has been done on the western part of the deposit and no serious effort has been made to find ore bodies east of the fault in the eastern part of the mine, although on the tenth, eleventh and twelfth levels some drifting was done along the fault and 62 feet from the south vein. It is not certain, however, that this ore is the continuation of the south vein. There is some evidence indicative of its

having once been a part of the north vein. If so, the horizontal offset of the fault must be nearly 400 feet.

The north vein where it curves toward the middle vein in the western part of the mine, instead of being nearly vertical, dips south and the indications are that both veins unite in depth along their whole lengths. This coalescence is probably due to the thinning and final disappearance of the layer of shale that separates the ore-bearing quartzite beds. By this stratigraphic disappearance of the shale lenses all three veins may in depth become one. The originally lenticular character of the shale layers probably furnishes also the explanation for the existence of only a single lode to the west. In that direction the deposit certainly diminishes in total width.

According to the engineers in charge, the ore body of the San Nicolas vein has a length of 1,082 feet on the twelfth level and extends as an almost untouched mass, 10 feet in average width, for 82 feet, up to the eleventh level. They give its average content as 8 per cent. of quicksilver.

In the San Francisco vein the ore body is about the same length as in the San Nicolas and is practically untouched between the twelfth and tenth levels. It is estimated also that 80 per cent. of the ore between the tenth and ninth levels is still in place, with an average width of 8.2 feet and a tenor of 8 per cent.

The San Diego-San Pedro ore body is 985 feet long and has scarcely been touched between the twelfth and eleventh levels. It varies in width from 17 to 36 feet, about 60 per cent. of this width usually being actual ore.

Whether the three ore bodies continue below the twelfth level in anything like the form that they have above that level is not known. The engineers in charge state that winzes sunk from 12 to 25 feet below the twelfth level reveal no change. On the other hand, my inspection of the twelfth level revealed irregularities in horizontal outline and in width that were not in evidence on the eleventh level. On the eleventh level the ore bodies are clean-cut and well-defined and stoping was proceeding sys-

tematically; whereas the twelfth level was in a disorderly condition and it was clear that the ore bodies are affected with vagaries in their form that have disturbed the time-honored methods of mining that had been followed for generations.

Grade of the Ore.—I was informed that the average mercury content of the ore is 8 per cent. and that the quantity of mercury in the ore reserves amounts to 15,000 metric tons, or about 33,000,000 pounds.

The figures given are clearly a mere approximation and attempts were made to check them. The data given show reserves of about 4,000,000 cubic feet of ore. A total content of 15,000 metric tons of quicksilver would give a tenor of only a trifle over 5 per cent. Records show that in the 16 years from 1901 to 1916 there was treated 207,550 metric tons of ore which yielded 17,926 metric tons of quicksilver. This gives a won tenor of 8.63 per cent. For a part of this period, from 1911 to 1916, there was treated 77,900 metric tons which yielded 6,795 metric tons, or 8.72 per cent. of quicksilver. The losses in distillation for a part of the plant are said to be only 2 per cent., but for a large part of the plant, the ancient Bustamente furnaces, a loss of 8 per cent. is confessed. I am inclined to believe, in view of the inadequate size of the condensation chambers, that 8 per cent. is a fair estimate of the average loss from the whole plant. That figure applied to the production for the 16-year period would give 9.32 per cent. as the grade of the ore going to the furnaces.

Another statement was made to me to the effect that during recent years 16,000 metric tons of ore has been required to produce 30,000 flasks of quicksilver. This corresponds to a won tenor of 6.47 per cent.

Costs and Methods.—The costs of mining and distillation have been steadily increasing at Almadén since 1910. The rise in the total cost per flask[2] is presented in the following table:

[2] The Spanish flask is an official measure of 34.507 kilograms, equal to 76.074 pounds avoirdupois.

COST PER SPANISH FLASK OF MERCURY PRODUCED AT ALMADÉN.

Year.	Cost in Pesetas.
1910–11	59
1911–12	62
1912–13	63
1913–14	75
1914–15	75
1915–16	85
1916–17	88
1917–18	125
1918–19	165

This notable increase in the cost per flask appears to be due almost wholly to the higher cost of mining. The cost of distillation has remained at nearly a constant level of 16 pesetas per flask for many years, varying between the limits of 12 and 22 pesetas, the high mark having been reached in the year 1905.

The total cost of operation and administration amounted to 3,425,000 pesetas in 1918, and I was informed that the costs per flask amounted in that year to 165 pesetas. This would mean a production of 20,750 flasks, or 716.02 metric tons. The quantity of ore treated in 1918 was 8,300 metric tons; hence the quicksilver recovered amounted to 8.62 per cent. of the weight of the ore distilled. This conforms exactly to the ratio of recovery per metric ton of ore in past years. It is notable that the output of the mine fell during 1918 to 8,800 metric tons, which is the lowest in 20 years.

The following table of annual credits provided by the Spanish government for the operation of the mine and the actual expenses for the same years is instructive:

CREDITS AND COSTS AT ALMADÉN.

	1904, Pesetas.	1913, Pesetas.	1918, Pesetas.
Credit provided	1,800,000	2,270,000	3,950,000
Total costs	1,775,000	2,270,000	3,425,000
Labor costs	1,250,000	1,760,000	2,775,000
Supplies	520,000	520,000	625,000

For 1919, according to the statement of the engineers in

[3] The peseta is equal to 19.3 cents.

charge, a credit of 5,000,000 pesetas has been granted, to which has been added a further sum of 2,000,000 for new equipment.

Although the tonnage treated in any year does not exactly correspond to the output of the mine, an approximate cost per ton may be obtained by dividing the total cost by the tonnage produced. This method of calculation gives a cost per metric ton in 1904 of 114.51 pesetas; in 1913 of 174.61 pesetas; and in 1918 of 398.20 pesetas. In 1918 the excess of ore produced over ore distilled was 500 metric tons; in 1904 it was 2,900 metric tons; while in 1913 the ore distilled exceeded the mine output by 3,500 metric tons.

The wages of miners have also increased rapidly. In 1900 they received 5.50 pesetas per day of 4½ hours and a total of 44.0 pesetas per month of 8 days; in 1919 the wages were 16 pesetas per day and 128 pesetas per month. The period of 8 days is the total number of days in each month that any driller is permitted to work. This regulation is the result of a time-honored custom said to be intended as a protection against the ill effects upon the health of laborers working underground.

In addition to this the miners are paid a bonus for one half of all ore extracted in excess of an amount fixed by the foreman as the minimum that each must produce, this amount varying with the character of the rock at the face where the miner is working. The formula used for calculating the bonus is:

$$\frac{\frac{a}{2} \times h}{b},$$

where a equals the basic wage,

b equals the quantity of ore that must be broken to earn the wage a,

h equals the excess broken over the fixed quantity b.

The bonus paid is sufficient to serve as an incentive for good work. The average output per man is said to be 0.133 cubic meter of ore per diem, and the average amount required per man comes to about 0.075 cubic meter per diem.

The total number of workmen employed in all situations outside of the distilling plant is 2,100, to which is added a force of 400 men during the period of 5 or 6 months of the autumn and winter of each year when the distilling plant is operated.

The costs of mining are enormously higher than necessary on account of the absurd system of filling approximately half of the volume excavated with solid brick and stone masonry arches and pillars. The veins stand vertically, with a slight sinuosity about a normal axis. The walls for the most part are sound, and will stand for considerable heights and for long periods of time without supports. There is, however, a tendency to swell and scale off if the open space between the walls is not filled, as often happens in any mine. Where the walls at Almadén exert any real pressure upon the masonry arches and pillars these are promptly crushed, as might be expected. To a limited extent ashes and cinders from the boiler houses are used as filling, these being introduced between the masonry pillars, supported upon extra arches. This filling is employed where unusual pressures are detected. If it should occur to those in charge to fill the mine with rock quarried on the surface and sent down into the mine through mill-holes, instead of continuing the century-old practice of filling with masonry, enormous economies could be effected at once. From 1900 to 1918 a total volume of 146,850 cubic meters of masonry filling has been constructed to replace a total quantity of ore extracted during the same period of 284,800 metric tons. A large part of the "waste" produced in mining is utilized in constructing the masonry, and the volume to be filled is, of course, much greater than that originally occupied by the ore hoisted. The fact that the greater part of this masonry stands uncrushed, and that it crushes wherever pressures are developed, demonstrates that it is not needed, and that bulkheading and filling portions of the mine with broken rock would be sufficient, resulting in a great saving of money.

Fortunately the mine makes but little water, the amount

hoisted per diem of 24 hours being only 80 cubic meters (21,009 gallons).

No automatic methods of handling ore or other materials, either above or below ground, are in use. A cable tramway from the "cerco" or mine yard to the distilling plant is the sole attempt at the application of modern methods. Ore is handled underground, and in most situations for loading and unloading above ground, in *esparto* baskets, following the almost universal custom at the mines in Spain. The hoisting works are old, uneconomical of power, and of small capacity. The surface plant is crowded within a narrow walled compound that dates back more than a century. The hours for work are ridiculously short. Even the reduction of the working day of the miners to a total of 4½ hours, 8 of which periods, or a total of 34 hours, constitute a month's work, for which a minimum of 128 pesetas, or roughly 70 cents United States currency per hour is paid, would appear to be an exaggeration of precaution. Better underground sanitation, better ventilation of the mine, the use of machine drills working wet, the introduction of a system of mining that would wholly avoid overhand stoping, the employment of high explosives instead of black powder, would enable the workman to earn comfortably a better wage. An increased output per man would result, as well as a reduction in the cost of the ore produced, and an improvement in the health and spirit of the miner who is suffering more to-day from being underfed than from being poisoned by mercury in the mine. The wages earned are insufficient for the maintenance of a man with family at the prevailing prices of articles of prime necessity in Spain. Equally fundamental reforms are needed in the distilling plant.

Administration.—The need of radical reforms at Almadén has been realized by Spanish engineers, and has been the subject of open discussion. It is, no doubt, because of adverse criticism of the archaic methods prevailing at Almadén, that the Spanish government has inaugurated a new system of administration. At the instance of a recent Minister of Hacienda (Finance), Señor Agusto Gonzales Besada, a Royal Decree was ap-

proved on June 25, 1918, whereby the control, administration, and management of the mine of Almadén was delegated to a Council, to be appointed especially for that purpose. The object of this change was to "industrialize" the enterprise and to free it from the paralysis of bureaucratic methods of adminstration with the expectation that the exploration and operation of the mine might be improved to the pecuniary advantage of the state as well as of the workmen.

The Council is allowed to borrow money for new installations, pledging the product of the mine in payment, and to engage a staff of experienced men at salaries commensurate with those paid high-grade engineers in privately owned and operated enterprises. The remuneration of the Council is contingent upon the reduction in the cost of production which they may achieve. They are entitled to a distribution among themselves, with a double portion accruing to the president of the Council, pro rata, of 8 per cent. of the sum saved under their administration in any year as compared with the average cost during the preceding 5 years. This method of remuneration would apparently have a curious effect, since the earning power of the members of the Council derived from the partition of moneys saved in cost of production could reach a maximum in a very short period and then decline under continued efficient administration. Outlay for betterments and additions to plant are specifically exempt from inclusion in the accounts for computing the economies effected. Under that system it would be logical to anticipate large expenditures for new equipment.

It is current gossip among the informed people at Almadén that the present sales-contract with the Rothschilds, which terminates in 1921, will not be renewed. The government will, it is said, undertake to dispose of its product in the open market, without the intervention of a commisssion house. The official price of quicksilver for Spain on July 11, 1919, was 340 pesetas per Spanish flask. The quotations in London at that time (fluctuation during the first 11 days of July) were from £10 to £19. There is nothing in the sales-contract to prevent the

disposal of the Almadén mine to private parties, irrespective of the anticipated profits under said contract, as was done with the Rio Tinto copper mine about 50 years ago.

The Almadén mine has always been under control of the state except for a period of 121 years, from 1524 to 1645, when it was delivered over to the German Counts John, James, and Marcos Fuggar (the Condes Fucares of the Spanish annals) in satisfaction of the remainder of a debt contracted by Charles I., this remainder amounting to 200,000 ducats. The only benefit that the state received during this period was an annual rental of 1,500 quintales of mercury (about 156,000 lbs.). The descendants of the Fuggars finally allowed the mines to fall into so dangerous a condition that it proved impossible to retain enough laborers to operate at a profit. The government resumed control, but the scarcity of workers still embarrassed the operation, the place having acquired a bad name. In order to overcome this prejudice and attract workmen the government announced a work-day of only 6 hours, for which a full day's wage would be paid, which was a temptation in times when 12 and 14 hours constituted a day's work. This seems to be the actual origin of the unusual period of labor that has become established in the mine of Almadén.

The engineers appointed under the new regime have an opportunity to introduce reforms and to proceed with new development that should enable them to produce at a greatly reduced cost and apparently to add large reserves of ore outside of what is now blocked and ready for stoping.

Production.—The ore at present in sight in the Almadén mine contains more than 3½ times as much quicksilver as the average yearly world's output of that metal. Almadén has been producing from 20 to 35 per cent. of the total world's output according to published figures. It can maintain its present rank for a decade and probably for a much longer time, independently of any further development of the mine. The following table has been compiled from records in the mine office:

PRODUCTION OF QUICKSILVER AT ALMADÉN.

Fiscal Year.	Metric Tons.	Fiscal Year.	Metric Tons.
1900–01	820	1908–09	1,235
1901–02	1,025	1909–10	1,200
1902–03	1,100	1910–11	1,240
1903–04	1,030	1911–12	1,240
1904–05	1,100	1912–13	1,240
1905–06	1,236	1913–14	1,025
1906–07	1,235	1914–15	1,025
1907–08	1,170	1915–16	1,025

Within the next three years the mine will be better equipped and more thoroughly developed. Accordingly, though some difficulties have been experienced during the last two or three years, evidently becoming more acute in 1918, the possibilities of immediate improvement in mining and metallurgic methods and in management are so great that it is to be expected that the new departure in administration, having in view the "industrializing" of the enterprise, may produce results that will greatly increase the importance of Almadén as a competitor and price-regulator in the mercury market.

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THE ORE OF THE ALMADÉN MINE.

F. L. RANSOME.

Rocks.—The general geologic relations of the ore of the Almadén mine have been described by a number of competent observers and are well summed up by Beyschlag, Vogt and Krusch,[1] who state:

> The mountainous country around, bare and unproductive, consists of Silurian and to a lesser extent of Devonian beds, which have been subjected to a moderately strong regional metamorphism. The Silurian beds which alone come into consideration in reference to the ore deposit, consist in their turn of clay-slates, intercalated limestones, and white to reddish quartzites which occasionally pass over to or become micaceous sandstones. In the clay-slates occur layers of schistose diabase tuff, known locally as *Piedra Frailesca* on account of its gray color which resembles that of the cloak of the Fraile Francisco religious order. Several intrusions of a diabasic or melaphyric eruptive rock are known, while granite, which in depth is probably more extensive, appears at a distance.

In the material collected by Mr. De Kalb only two of the rocks mentioned above are represented—the dark clay slate and the quartzite. Certain specimens, collected from apparently dike-like masses that were pointed out to Mr. De Kalb, as *frailesca*, proved, when seen in thin section, to be quartzite, either of darker color than most of that rock or of generally different appearance in consequence of crushing. Mr. De Kalb consequently is inclined to believe that the *frailesca*, as a distinct rock, has no existence. Its description, however, by Helmhacker[2] and other petrographers, although their work was done many years ago, is too clear and detailed to permit me to concur in this

[1] "Ore Deposits," Truscott's translation, vol. 1, p. 475. Macmillan, 1914.

[2] Helmhacker, R., "Ueber den diabas des Almadenfeldes," *Zeits. f. d. B.-H-u. Salinenwesen im Preussen*, vol. 28, p. 126, 1880.

conclusion. Noggerath[3] states that the San Teodore shaft is entirely in the *frailesca* and such geologic level-plans as have been published in the Estadistica Minera de Espana support his statement. On the other hand the ore bodies themselves appear to come into contact with this rock only in very few places. The diabase, or "porphyry" of the official mine reports, also appears to be uncommon in the immediate vicinity of the ore.

The slate represented by specimens in Mr. De Kalb's collection presents no unusual characters. It is dark gray, with the fine grain common in rocks of its class and is not particularly fissile. Under the microscope, in thin section, it appears as a very fine aggregate of quartz, sericite, a little zircon and considerable cloudy, dark carbonaceous material.

The normal quartzite of the mine is a hard, fine-grained rock of so light a gray tint that it would ordinarily be referred to as white quartzite. The microscope shows that many of the quartz grains are in close, interlocking contact while others are separated by interstitial aggregates of sericite. Some of the thin sections examined show very distinctly the original rounded outline of the detrital quartz grains, which have been enlarged in the well-known manner by the addition of new quartz in optical continuity with the old. Rounded crystal grains of zircon are fairly abundant. Some of the specimens of quartzite that appeared at first glance to be wholly unmetallized were found on close inspection to contain a little pyrite and to show dew-like droplets of native quicksilver on fracture surfaces. Such specimens generally contain also a few microscopic specks of cinnibar. Certain very dark specimens, scarcely recognizable as quartzite and labelled "frailesca," when examined in thin section were found to differ from the white quartzite chiefly in the presence of disseminated specks and flocculent aggregates of dark, nearly opaque and apparently non-crystalline material which occurs interstitially with reference to the quartz. A small

[3] Noggerath, A., "Mitteilung uber die Quecksilberwerke zu Almadén und Almadén ejos in Spanien nebst einem Uberblick der Vorkommen von Quecksilber im algemeinen," *Zeit. f. d. B.-H-u. Salinenwesen im Preussen*, vol. 10.—, 1862.

fragment of this rock powdered and treated with chloroform, by Mr. E. T. Erickson in the chemical laboratory of the U. S. Geological Survey, gave a slight residue on evaporation of the solvent. Another portion heated in a closed tube gave a distinct odor indicative of the presence of bituminous material. The quantity available for tests was too small to yield wholly satisfactory results, but it appears fairly certain that the dark material is a hydrocarbon. It is associated with considerable finely disseminated pyrite. In some specimens of the quartzite the quartz grains are turbid with minute inclusions, in part liquid inclusions with bubbles. Some of these are arranged along roughly parallel lines in a way that suggests their origin as a consequence of strain in the rock.

Ores.—All of the ore specimens examined, including one that was supposed to represent the occurrence of cinnabar in crushed slate, proved to be metallized quartzite.

Various opinions have been held as to the mode of introduction of the cinnabar into the quartzite. De Prado[4] as early as 1855, described the cinnabar as having partially replaced the quartzite. Becker[5] could see no evidence of replacement. According to him the cinnabar fills fissures in the quartzite or occupies pores in the rock. Beck,[6] who gives a drawing of the ore as seen in thin section, agrees with de Prado that the cinnabar has in part replaced quartz. He appears to believe, however, that the quartzite has undergone recrystallization during the deposition of the cinnabar, a conclusion, which, if correct, does not seem to be consistent with the replacement hypothesis.

That there has been some deposition of quartz in the transformation of a sandstone, consisting of worn detrital grains into a quartzite in which the grains fit closely together as a quartz

[4] Prado, Casiano de, "Sur la géologie d'Almadén, d'une partie de la Sierra Morena et des montaignes de Toléde," *Bull. de la Soc. Géol. Franç.*, 2d ser., vol. 12, pp. 183–204, 1855.

[5] Becker, G. F., "Quicksilver Deposits of the Pacific Slope," Monog. U. S. Geol. Survey, vol. 13, p. 30, 1888.

[6] Beck, Richard, "Lehre von der Erzlagerstätten," 3d ed., Berlin, 1909, vol. 1, p. 521.

mosaic is evident. Some thin sections do not reveal the outlines of the original rounded grains. Others, however, do and show the original sand particles enlarged by the deposition of quartz in optical continuity with the older central portion. The fact that the shadowy outlines of the detrital grains are still recognizable indicates that the quartzite as a whole has not recrystallized. Had it done so not only would the outlines have been obliterated but the texture of the rock would probably be different. It would indeed be a remarkable coincidence if recrystallization should produce a rock of the same texture and the same evenness of grain that result when a sandstone is converted into a quartzite by the familiar process of granular enlargement through the deposition of quartz in crystalline continuity with the original grains. The expected result would be an aggregate of coarser or finer grain than the original rock or one in which the grain varies considerably from place to place.

The question now arises was the cinnabar deposited before, during, or after the general transformation from sandstone to quartzite? The answer is most likely to be found in a study of the lean ore or slightly metallized quartzite.

Examination of thin sections of lean ore under a low power of the microscope, brings out very clearly the dependence of deposition, in its early stages, on fissuring. The cinnabar is seen to occur along innumerable branching irregular fissures. Noticeable features of these fissures are their small size and their very general distribution through the rock. The fissuring is minute in texture and in places the quartz granules appear to have been shaken loose along their surfaces of contact and the deposition of cinnabar in the resulting openings has produced a delicate fine-textured mesh or web, in which the quartz grains appear to be held. The general appearance of such comparatively low-grade material is shown in figure 21, made by photographing a thin section with low magnification and tracing the outlines of the cinnabar from the photograph. The illustration shows clearly that the deposition of cinnabar began in a network of minute fissures. It is equally clear that deposition

was not confined to the fissures but took place partly at the expense of the quartz itself. The general texture of the lean ore, as here illustrated, proves, moreover, that the cinnabar could not have recrystallized during a general recrystallization of

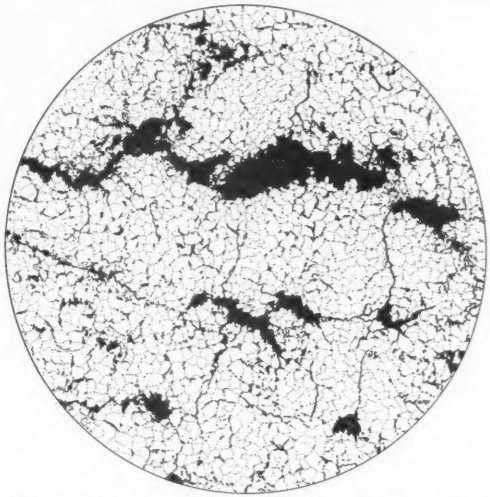

FIG. 21. Comparatively lean ore from the Almadén mine. Black areas are cinnabar. White is quartzite. Light-dotted lines indicate boundaries between quartz grains. Magnification 6.

the quartzite; had it done so the delicate network of cinnabar veinlets could not have formed. As some of the small veinlets cut through the quartz enlargements of the original clastic grains the fissures were probably formed after the deposition of the younger quartz.

Close inspection of the cinnabar veinlets under moderate or high powers of the microscope show them to be very irregular in width, the cinnabar projecting into the quartz in a manner that can be explained only on the supposition that the cinnabar has grown at the expense of the quartz. In a series of thin sections all gradations can be traced between quartzite that contains a few very small veinlets of cinnabar to those in which the

quartz appears as residual grains, with irregular embayed outlines, isolated in masses of cinnabar. Figures 22–24 were made with the aid of the camera lucida to illustrate steps in this gradation.

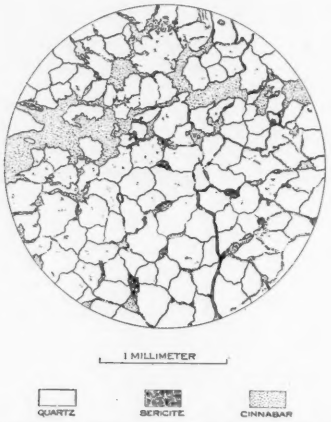

FIG. 22. Comparatively low-grade ore from the Almadén mine, showing early stage in replacement of quartzite by cinnabar.

Figure 22 shows the appearance of the ore in a comparatively early stage of replacement. The deposition of cinnabar has taken place partly in distinct fissures and partly along the surfaces of contact between the quartz grains. In the upper part of the figure replacement has made considerable progress and some of the quartz grains with irregular margins that are clearly the result of attack by the ore-depositing solutions, are isolated in the cinnabar. The specimen from which the illustration was made is from the twelfth level and by its bright red color suggests a larger proportion of cinnabar than the microscope shows to be present. Figure 23 shows the appearance under the microscope of a thin section of considerably richer ore. The locality from which this was collected was not recorded but it probably came from the eleventh or twelfth level. In this specimen the attack on the quartz grains has made further progress and a

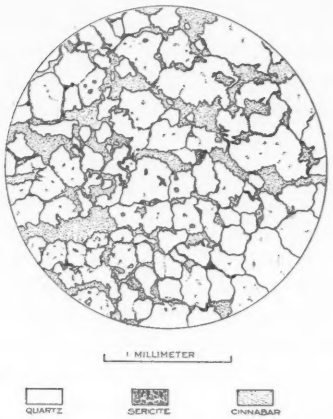

FIG. 23. Ore from the Almadén mine showing intermediate stage of replacement of quartzite.

larger numbers of grains than in Figure 21 appear as corroded remnants enclosed in cinnabar. Figure 24 was made from rich ore for which no locality is given but which probably also came

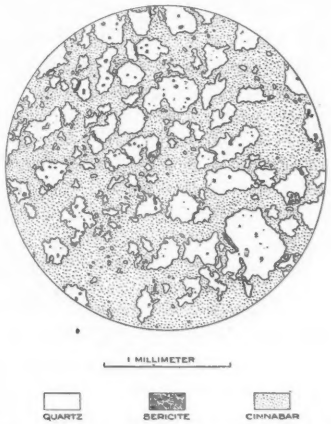

FIG. 24. Rich ore from the Almadén mine showing advanced stage of replacement of quartzite by cinnabar.

from the eleventh or twelfth level. Here the quartz occurs only as residual grains whose outlines show that it has been attacked and replaced by cinnabar.

Although the replacement has begun generally along distinct fissures and in the surfaces of contact of the quartz grains, nearly all thin sections of metallized quartzite show more or less cinnabar as minute particles within the apparently solid quartz. In some specimens these particles, as seen in thin sections, are few and scattered; in others they are more abundant and, as Beck has shown, may be arranged in nearly parallel layers which, as seen in section, appear as lines of dots. Beck appears to have interpreted these inclusions as showing contemporaneous crystallization of quartz and cinnabar. They are not confined, however, to the younger quartz but occur also in the clastic grains. As seen in thin section, lines of the tiny red specks may run indifferently through both the older and younger quartz and even from one grain to another. The occurrence of the inclusions in nearly parallel zones that are obviously quite independent of the crystal structure of each quartz grain suggests that the opportunity for their introduction was provided by external stresses after the crystallization of the quartz. According to this view the brittleness of the quartzite rather than its porosity was the determining characteristic in ore deposition. Supposedly the quicksilver-bearing solutions penetrated the quartz along exceedingly minute cracks which were afterwards healed by new quartz and thus in general rendered invisible. In a few instances, however, it has been possible with the microscope, to recognize such healed cracks along which occur little specks of cinnabar. Obviously such particles of cinnabar which, in a thin section cut across a fissure would appear as a line of red dots, would, in a section parallel with the fissure, appear to be scattered broadcast through the quartz grain. By focusing up and down with high power within the thickness of the section, it can frequently be ascertained that apparently scattered particles of cinnabar are really arranged approximately along planes. In addition to the cinnabar particles, some sections show minute liquid inclusions,

many of them with bubbles, and tiny globular beads of an opaque material, probably a hydrocarbon, which in their distribution and arrangement are closely similar to the cinnabar. These three kinds of inclusions in the quartz may occur separately along different lines or zones or may all occur together in the same zone.

In addition to cinnabar, quartz, and sericite, most thin sections of the metallized quartzite or of ore show a very little disseminated pyrite and occasional rounded crystals of zircon. Barite occurs with some of the ore but was not seen in the thin sections examined.

In connection with the examination of the ore, a thin section was made of some calcined quartzite from one of the furnace dumps. Under the microscope the material which could never have been rich ore, shows surprisingly little effect of passage through the furnace. Quartz and sericite fit closely together and there are no conspicuous cavities or pores. Evidently rich ore, such as shown in Fig. 24, would be represented on the furnace dump by very porous material or, more probably, by sand. Examination of the calcined quartzite under high power shows that of such cinnabar as it originally contained a considerable part still remains in the rock as minute inclusions in the quartz grains. The quicksilver extraction at Almadén is clearly not complete.

In conclusion, the cinnabar of the Almadén mine is not to any considerable extent deposited interstitially in originally porous rock but has been introduced into the quartzite through innumerable small fissures and has extensively replaced both the quartz and the interstitial sericite of the quartzite. According to this view, the sericite was formed before the deposition of cinnabar. The deposit, therefore, is not to be classed, as it sometimes has been, with those in which cinnabar occurs as an impregnation of porous sandstone.

U. S. Geological Survey,
Washington, D. C.

NOTES ON TEXTURES AND RELATIONSHIPS IN THE GLOBE COPPER ORES.

G. M. SCHWARTZ.

INTRODUCTION.

This paper describes a set of ores from Globe, Arizona, in the collection at the University of Minnesota, and one supplied through the courtesy of Richard N. Hunt, who at the time this paper was in preparation was engaged in the examination and study of a group of Globe properties. I am indebted to Prof. W. H. Emmons and Prof. F. F. Grout for suggestions and criticisms.

SUMMARY OF THE GEOLOGY OF THE GLOBE DISTRICT.

The Globe district has been described by F. L. Ransome[1] and others.[2] It is an area of schist and other pre-Cambrian rocks which are overlain unconformably by Paleozoic rocks ranging from the Cambrian to the Carboniferous and consisting of shale, conglomerate, quartzite, dolomite, and limestone. The pre-Cambrian and Paleozoic rocks were intruded, probably during the Mesozoic, by diabase and by smaller masses of granite and quartz monzonite. All were then covered by a flow of dacite. Faults are numerous; some are older, others younger than the dacite. These faults have shattered the country thoroughly. Ransome has termed the area one of "regional brecciation."

The ores of the type described occur as lodes in schist, quartzite, limestone and diabase. The diabase forms part of the foot-

[1] Ransome, F. L., "Geology of the Globe Copper District," U. S. Geol. Survey Prof. Paper 12, 1903; *Min. and Sci. Press*, vol. 100, p. 256, 1910; *Min. and Sci. Press*, vol. 102, p. 747, 1911; U. S Geol. Survey Bull. 529, pp. 183–186, 1913.

[2] Tolman, C. F., Jr., *Min. and Sci. Press*, vol. 99, p. 646, 1909.
Tovote, W. L., *Min. and Sci. Press*, vol. 108, p. 487, 1914.

wall, and in places, the hanging wall in the Old Dominion Mine. Limestone usually forms the footwall where the diabase is absent.

Other types of ores are disseminations in the Pinal schist, and secondary deposits of chrysocolla in the dacite and in fissures.

The primary ore consists of pyrite, chalcopyrite, specularite. and bornite. The bornite is probably both primary and secondary. The close association of the diabase and the ore in the Old Dominion suggests a genetic connection. The ores are oxidized to great depths. In the Old Dominion Mine the oxidation is prevalent to 800 feet and extends in some cases to 1,600 feet.

Conditions indicate that the oxidation took place, at least in part, previous to the deposition of the Gila conglomerate. Under the oxidized ores are bodies of chalcocite enriched ore which grade down into pyrite, chalcopyrite, and bornite. When Ransome prepared Professional Paper 12, in 1902, bornite had not yet been found, but it apparently is now one of the chief ore minerals in the deep levels. It may be mainly hypogene, but also is definitely supergene in part.

ORES.

The common ore minerals are pyrite, chalcopyrite, bornite, chalcocite, cuprite, chrysocolla, malachite, melaconite, specularite, native copper, limonite, and azurite. Other minerals[3] are enargite, brochantite, sphalerite, galena, cerussite, wulfenite, cuprosedcloisite, argentite, cerargyrite; but these are not abundant in the copper ores and were not observed in the limited collection of typical copper ores.

Pyrite.—This mineral is abundant in the unoxidized zone of most ore bodies. It is likewise present to a lesser extent in the oxidized zone. It was examined in specimens from the 9th, 12th, 14th, 15th and 16th levels of the Old Dominion Mine and in three specimens from the Iron Cap Mine.

Plate XI. *A* shows the replacement of pyrite by chalcocite. All stages in the replacement were found from the essentially unal-

[3] Tovote, W. L., *Min. and Sci. Press*, vol. 108, p. 488, 1914.
Ransome, F. L., U. S. Geol. Survey Prof. Paper 12, p. 120.

tered pyrite to a point where only a few rounded, corroded fragments of pyrite remain in the chalcocite. Typical examples of the fragmental structures described by Graton and Murdock[4] are found. In the early stages the pyrite grains are not only corroded but are cut by clearly defined veinlets of chalcocite. All stages of these may be found in single specimens. Almost perfect microscopic crystals of quartz are found in the chalcocite in the specimens which show the alteration described. It is noteworthy that the minerals which at other districts have been noted as intermediate between pyrite and chalcocite are absent in all the specimens of the Globe district that are available. Pyrite was found as scattered grains in one bornite-chalcocite specimen. The grains were rounded as were the residual grains in other specimens. Plate XI. *B* shows very clearly the replacement of pyrite by limonite.

From the observations recorded, it is clear that pyrite, almost without exception, is replaced directly by chalcocite as indicated by Ransome.[5] There is no proof in the polished specimens of the chemical nature of the replacing solutions, but the end result is seen. In some cases the pyrite escaped alteration by copper solutions and consequently alters, possibly at a later time, to limonite as illustrated by Plate XI. *B*.

Chalcopyrite.—Chalcopyrite is not, in general, as abundant as pyrite. It was examined in ores from the 15th and 16th levels of the Old Dominion Mine and in several specimens from the Iron Cap Mine. A common occurrence is with a quartz gangue; tiny veinlets of quartz cut the ore in all directions. A specimen from the 16th level showed veinlets of bornite cutting the chalcopyrite, Plate XI. *C*. The bornite in general followed the quartz veinlets, but also cut across the chalcopyrite in other places. Chalcocite was not observed directly replacing the chalcopyrite, although it commonly replaces pyrite and bornite.

The association of bornite with quartz in the chalcopyrite indicates that the bornite alteration followed the contact of the

[4] Graton and Murdock, *Am. Inst. Min. Eng. Trans.*, vol. 45, pp. 26–81, 1913.
[5] Ransome, F. L., U. S. Geol. Survey Prof. Paper 12, p. 129.

gangue and ore. It is characteristic of replacement to start along these contacts, as can be observed in many known associations of primary and secondary minerals. The quartz may be hypogene or supergene but the occurrence of quartz veinlets cutting chalcocite indicates that it is of late age in this type. The similarity of occurrence of the quartz between the chalcopyrite, bornite, and chalcocite speciments offers strong evidence that the bornite in chalcopyrite is supergene. The relation of the bornite to chalcocite in replacing chalcopyrite gives additional proof.

Bornite.—This mineral is abundant in the lower levels of the Old Dominion and other mines. The significant fact that it had not been detected in 1902 has been pointed out. The Old Dominion was then explored to the 12th level. Specimens studied from the 15th and 16th levels, as well as others from the Iron Cap Mine, show abundant bornite. The bornite commonly occurs with quartz gangue, at some places replacing chalcopyrite. Many specimens show no evidence of residual pyrite or chalcopyrite. The bornite is characteristically replaced by chalcocite as noted below.

The fact that much of the bornite shows no residual minerals indicates that it is hypogene, and it has been thus described.[6] Graton and Murdock[7] state that bornite, as a rule, is a primary residual mineral and when secondary is usually confined to the lower part of the zone of enrichment. This may explain its abundance in the lower levels of the Old Dominion where it is entirely absent from the upper levels. The deep oxidation at Globe would account for its absence above. In the lower levels it might be supergene or hypogene. The evidence cited above shows that it is in part supergene. There is no reason to believe that it is not in part hypogene.

Chalcocite.—This mineral is abundant in the unoxidized ores. Specimens were examined from the 6th, 9th, 12th, 14th, 15th and 16th levels of the Old Dominion, and in several specimens from the Iron Cap Mine.

The replacement of pyrite by chalcocite has been described

[6] Tovote, *Min. and Sci. Press*, vol. 108.

[7] Graton and Murdock, *Am. Inst. Min. Eng. Trans.*, vol. 45, p. 30, 1913.

under pyrite. It need only be emphasized here as one of the evidently characteristic processes at Globe. Fully as common in the lower levels is the replacement of bornite by chalcocite. This is present in all degrees from small areas along the gangue in the bornite-chalcopyrite-quartz specimens to a stage where only small remnants of bornite remain which show the fragmental structure. Plate XI. *D*, shows this replacement.

A specimen from the 6th level of the Old Dominion showed the replacement of chalcocite by malachite in a remarkable system of veinlets and needle-like forms. (Plate XI. *E*.) Many specimens, notably those from the 14th level of the Old Dominion, showed a skeleton or spongy network of quartz as described by Laney.[8] He believes this to indicate contemporaneous deposition, which seems the most reasonable explanation. A specimen from the 9th level, showing ore in quartzite breccia, has native copper in the chalcocite. This is not common in the chalcocite, but is common in the cuprite.

Etching the chalcocite with HNO_3 and KCN revealed only the typical orthorhombic cleavage. Some of this in the pyrite-chalcocite specimens was of the very fine type decribed by Tolman.[9] He believes that this indicates deposition in a metacolloid state. His figures show the various etch cleavages. In the bornite-chalcocite specimens coarser crystallization was shown, but all apparently orthorhombic, indicating that the replacement of the bornite did not take place along cleavage planes. This is also strongly indicated by the veinlet type of replacement figured. In general the chalcocite appears to be supergene.

Cuprite.—Cuprite associated with various other minerals of the oxidized zone is one of the abundant forms of ore. This is especially true of soft ore of cuprite, hematite, and limonite. Specimens were examined from the 6th, 9th, 10th, 14th, 15th, and 16th levels of the Old Dominion and several specimens from the Iron Cap Mine. As one would expect, the cuprite ores showed great complexity, specimens often containing malachite, chryso-

[8] Laney, F. B., "Relations of Bornite and Chalcocite in the Copper Ores of the Virgilina District," *Proc. U. S. Nat. Museum*, vol. 40, p. 518.

[9] Tolman, C. F., Jr., *Am. Inst. Min. Eng. Trans.*, vol. 48, p. 401.

colla, black oxide, azurite, and pyrite. Veinlets cutting the cuprite showed a series of minerals deposited as the oxidizing solutions changed.

Malachite.—This mineral is likewise abundant in the oxidized zone. Specimens of malachite and hematite forming soft ore are not uncommon. The association of malachite, limonite, chrysocolla, and cuprite in concentric or pisolitic structures is notable. A network of veinlets of malachite cutting cuprite is frequently observed.

A specimen from the 15th level of the Old Dominion showed the variation that must have occurred in the oxidizing solutions. The main mass of cuprite is cut by a veinlet with the minerals in the following order; black chrysocolla, green chrysocolla, melaconite, malachite. (See Fig. 25.)

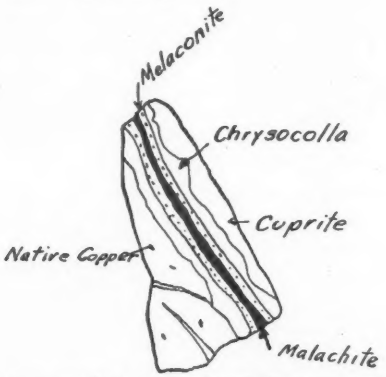

FIG. 25. Veinlet in oxidized ore in altered limestone, 15th level, Old Dominion Mine.

Chrysocolla.—This is an abundant mineral in the oxidized zone. Not only the characteristic blue, but the black silicate is found. It is, as a rule, in veinlets, or in the pisolitic structures so abundant in the oxidized zone.

PISOLITIC OR CONCENTRIC STRUCTURES.

Examination of the polished surface of oxidized ores showed many concentric structures not described in the literature on the

district. These structures vary from microscopic size to one-half inch or more in diameter and show rounded, but as a rule only semi-spherical, outlines. There is no uniform sequence of arrangement of the minerals but quite the contrary. The common minerals in the concentric arrangement are cuprite, chrysocolla, malachite, limonite, and melaconite. The larger type appear to be of two kinds, those with a malachite center surrounded by limonite with more or less cuprite and malachite forming the matrix, and those which show only limonite. Some show exceptional banding in the limonite.

The microscopic structures showed even more variety than the larger ones. The cones in some are of malachite, cuprite, or even chrysocolla (Plate XI. *F*). In some, the series from inside out is: cuprite, malachite, limonite, embedded in a matrix of cuprite. Others show malachite surrounded by limonite, or chrysocolla, malachite and limonite in order; still others are found with chrysocolla and limonite.

The larger structures show limonite with concentric banding, suggesting that the limonite represents areas that were formerly pyrite. The limonite replacing pyrite indicates this is a possibility. Some show a malachite core, which is probably not the original core, but represents the pyrite which failed to alter to limonite before the solutions became more or less carbonated and more or less cupriferous.

The fact that such a variety of arrangement is shown indicates that the concentric feature is the result of a process especially characteristic of the oxide zone. Perhaps it is also common in the supergene ores, but fails to show where the color contrasts are low. There are descriptions of the alteration on a large scale of one mineral to another, in concentric zones,[10] but few of microscopic size. Perhaps, this is due to the fact that most of the work on polished specimens has been confined to the study of the sulphide ores. Ransome[11] also mentions a concentric structure in chalcocite after pyrite in the Globe ores. In the set of specimens described here these structures were not found.

[10] Emmons, W. H., "Enrichment of Ore Deposits," U. S. Geol. Survey Bull. 625. Bateman and McLaughlin, ECON. GEOL., vol. 15, pp. 1–80, 1920.

[11] *Loc. cit.*, p. 121.

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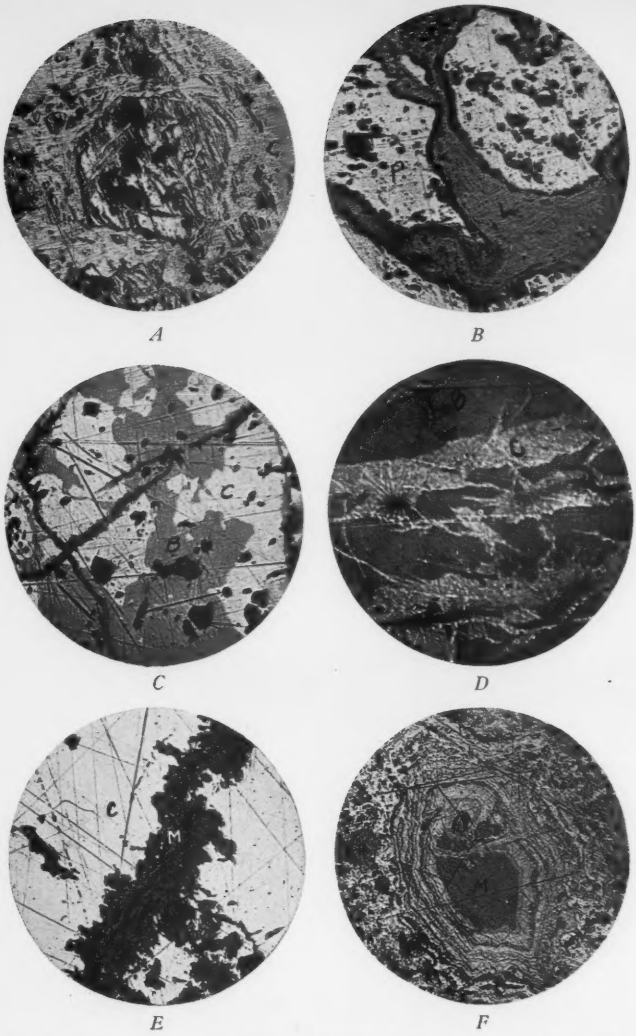

A

B

C

D

E

F

A. Pyrite (P) partly replaced by chalcocite (C). Note crystal outline of pyrite, also rounded fragments of chalcocite. Twelfth Level Old Dominion Mine. × 65.

B. Pyrite (P) altered partly to limonite (L). Process similar to *A* but solutions produced no enrichment. Ninth Level Old Dominion Mine. × 65.

C. Chalcopyrite (C) partly replaced by bornite (B). Bornite follows quartz veinlets. Same specimen also showed chalcocite replacing bornite. Sixteenth Level Old Dominion Mine. × 60.

D. Bornite (B) partly replaced by chalcocite (C). Iron Cap Mine. × 65.

E. Chalcocite (C) cut by malachite (M) veinlet. Sixth Level Mine. × 63.

F. Concentric structure with malachite core (M) surrounded by limonite and malachite. Note Cuprite (Cu). Fourteenth Level Old Dominion Mine. × 63.

The general occurrence of these structures in a typical oxidized deposit suggests that oxidation processes result in a concentric arrangement of the constituents, not only as regards the various constituents which are radially arranged, but within each mineral; this is conspicuously shown by the limonite.

SUMMARY.

1. The primary ores of Globe are of two distinct types. Pyrite ore and chalcopyrite-bornite ore. These types are, as a rule, clearly differentiated.

2. Secondary enrichment has been an active process which went on as two distinct processes determined by the type of primary ore.

3. Pyrite has been replaced by chalcocite without intermediate minerals. Ransome's conclusions as to the importance of that process are supported.

4. The chalcopyrite primary ore has been replaced by bornite in some cases, and the bornite, both primary(?) and secondary, has been replaced by chalcocite.

5. Both types of enrichment have resulted in rich ore bodies in the deep levels in this district.

6. Chalcocite has been replaced by malachite in some cases, but the normal oxidized ore showed cuprite, often cut by veinlets of chrysocolla, malachite, melaconite, azurite.

7. The paragenesis is essentially as given by Ransome: pyrite, chalcopyrite, and bornite, primary and contemporaneous. Secondary minerals in order: bornite, chalcocite, malachite; or chalcocite, cuprite, native copper, chrysocolla, melaconite, malachite, azurite.

8. Concentric structures are characteristic of the oxidized ores.

9. The Globe ores show in a simple manner and with exceptional clearness the common processes of deposition, replacement, supergene enrichment, and oxidation of copper deposits.

UNIVERSITY OF MINNESOTA,
MINNEAPOLIS, MINN.

EDITORIAL

THE JOURNAL'S SUBSCRIPTION LIST

After fifteen years of active life it is of interest to glance over the list of subscribers to our journal in order to discover whether it has made for itself a place in the periodical scientific literature of the country. Was it needed? Have its efforts to furnish a readable magazine been appreciated by the geological fraternity? Is it of sufficient value to warrant a continuation of the work being done upon it by the men who are responsible for its existence? A study of its mailing list answers these questions in the affirmative.

It must be confessed that the journal is not yet continually self-supporting. Were it not for the help being given it by Yale University and the University of Illinois it would in most years not be able to pay its running expenses, even though there are no charges against its income for salaries. However, had there been no increase in printing and illustrating costs during the past three years all expenses would have been paid by subscriptions.

It is a matter of some pride to know that Economic Geology has become an international journal. At present every State in the Union and all of its dependencies except Guam and Porto Rico are represented by subscribers and the names of fifty-seven countries are on its mailing list.

Probably the most interesting result of the study of the mailing list has to do with the effect of the war on the distribution of domestic subscribers. Although the journal appeals to a comparatively few specialists, its clientele is so widely distributed that any disturbance of the normal current of events is discernible in the changing habitat of its readers. During the war interest in petroleum became intense. There was a call for geol-

ogists to investigate new oil fields and many abandoned their old professions and entered new fields. During this period the number of subscribers in Texas increased 600 per cent., in Oklahoma 350 per cent., in Kansas 400 per cent., in Louisiana 350 per cent., in Kentucky 400 per cent. and in California 35 per cent. There was a reduction of 17 subscribers in the District of Columbia, of 8 in Michigan, of 5 in New York, and of 3 each in Idaho, New Mexico and Wisconsin. These figures show clearly the drift of mining geologists into the oil fields.

New York, California, Texas, Oklahoma, Pennsylvania, District of Columbia, Colorado, Illinois, Massachusetts, Arizona, Kansas, Minnesota, Utah, Ohio, Montana and Louisiana are the most prominent State names on the mailing list. Five years ago Texas, Oklahoma, Kansas and Louisiana would not have appeared in this connection. In this period the circulation of the journal has increased 13.7 per cent., but this increase is due largely to subscriptions from the oil companies and from individual oil geologists. There has been little growth of circulation among mining geologists.

When we turn to the inspection of the foreign list we are met by some surprises. The increase among foreign subscribers has been 37 per cent., mainly by expansion into countries to which the journal was a stranger before the war. The increase is due largely to the spread of geologists to the farthest corners of the world's recesses, mainly in the search of oil. Austria, Cuba, Russia, Turkey, Germany and a few other countries were dropped from the list, while there were added Algeria, Bohemia, Bulgaria, Costa Rica, Dutch Guiana, East Africa, Finland, Gold Coast, Greece, Ireland, Uganda, and Portuguese West Africa. The losses of individual subscriptions are in the countries that were stunned by the war.

The most significant fact relative to foreign subscriptions is the distribution of the subscribers. The loss in Germany, Austria and Russia between 1915 and 1920 has been 13 per cent. of the entire subscription in 1915. The gains in other countries have been 47 per cent. in the same period. Japan heads the list.

Here the increase has been 90 per cent. Other large increases are shown by Mexico, where because of the more tranquil condition there prevailing the increase has been 3½ fold. China has doubled, as have also India, New Zealand, Sweden, and the Dutch East Indies. Holland has increased 6 fold. This is accounted for largely by the increasing interest in oil.

If the reading of technical journals by the followers of a profession is a measure of progressiveness, the Japanese geologist must be conceded to be progressive to a marked degree, for more copies of the journal regularly enter Japan than are sent to England, Canada and Mexico combined. Australia, China, India, Holland, the Dutch East Indies and Sweden follow these three in order. Of the nations in Europe France is the laggard. Only two copies go to France. The current volumes are not to be found in a single library in that country, nor are the names of French geologists among those of the men who are now scouring the world for new ore deposits. Is this symptomatic? Is the French mining engineer disappearing? Or is the interest of the French geologist mainly along theoretic lines? The strongest contrast on our mailing list is Japan with 124 subscribers and France with two. Does the wide circulation of the Journal in Japan mean that the interest of the Japanese in applied science, as contrasted with pure science, is greater than that of other nationals, and is the Japanese geologist preparing himself for more intensive development of territory? Or is he merely aiding his country toward greater enlightenment by the use of applied science?

BUSINESS EDITOR.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

GEOLOGY OF THE ORE DEPOSITS OF KENNECOTT, ALASKA

Sir: In a paper by Messrs. Bateman and McLaughlin on the "Ore Deposits of Kennecott," which appeared in Vol. XV., 1920, of your Journal, a statement appears, on page 71, par. 4, which refers to the power of limestone to inhibit the formation of secondary chalcocite. Further, following general statement, it is said that "the absence of malachite, azurite, or basic sulphates in the limestone walls, *unconnected with sulphides,* and especially along the little veins of chalcocite isolated in the limestone, is a strong argument against the formation of the chalcocite from descending copper sulphate solutions."

In an investigation of the copper deposits of the Sable Antelope Mine, in Rhodesia, where I am now engaged, and which has only just been started, I have found in one case evidence that appears to be somewhat different to the above. In this particular mine that I refer to, the chalcocite is undoubtedly of supergene origin; the usual criteria of secondary enrichment are present. The ore occurs in a dolomitic limestone of which at least 100 feet have been swept away by erosion; the larger bodies of ore occur at a vertical distance of roughly 50 feet; thus the copper sulphate solutions have had at least 150 feet of limestone through which to journey. The larger masses of chalcocite are quite free from any of the carbonates or sulphates and from one stope over

1,000 tons of this carbonate-free sulphide was extracted. The carbonates and sulphates are confined to a few oxidized zones where fissuring has allowed of the ready passage of oxygenated waters, and there they occur in very small quantities. Azurite is generally absent but malachite forms pseudomorphs after *orthorhombic* chalcocite.

R. MURRAY-HUGHES.

SABLE ANTELOPE MINE,
VIA NUMBWA,
N. RHODESIA.

THE ORIGIN OF GRAPHITE.

Sir: As one interested in the origin of graphite, I regard the two papers on the subject that appeared in the April–May number of this Journal by Clark[1] and Tilley[2] as important contributions. The many ways in which graphite is known to occur render conclusions regarding its mode of formation a difficult matter, and it is to be expected that opinions differ. Consequently these papers are to be welcomed as making it possible to approach the truth nearer than ever before.

The report on the Adirondack graphite deposits[3] was based upon field work undertaken during the summer of 1917, when a commercial rather than a purely scientific emphasis was the main motive. Consequently many details regarding the contact type of deposit, which Clark desires, could not be included. In examining this type of deposit I was impressed with the occurrence of graphitic-bearing sedimentary rocks associated with or in the immediate neighborhood of the contact zones. The granitic pegmatites that functioned as one of reagents in the ore-formation process could in many instances be proved to be penetrating and cutting these sediments. Since that time this observation has been amplified. The contact form of the mineral seems to have been brought about by a soda-granite pegmatite intruding

[1] Clark, Thomas H., "The Origin of Graphite," ECON. GEOL., vol. 16, 1921, pp. 167–183.

[2] Tilley, C. E., "The Graphite Rocks of Sleaford Bay, South Australia," ECON. GEOL., vol. 16, 1921, pp. 184–198.

[3] Alling, H. L., N. Y. State Mus. Bull. 199, 1918.

and passing through graphitic-bearing crystalline limestones or other graphitic sediments.

The remark, which Clark quotes,[4] that CO_2 could have been derived from the limestone through which the pegmatites passed was suggested in the report without having sufficient data to justify carrying it any further. Both Clark and Tilley[5] emphasize this point. Additional information has been secured and I am inclined to believe that there is considerable value to be attached to Clark's conclusion. However, it is well to observe that the limestones in the Adirondacks which could have furnished the carbon dioxide are in nearly every instance graphite bearing and not pure calcareous sediments. All of the available evidence supports the opinion that the graphite in these crystalline limestones was derived from organic matter in the original lime muds. In the few exceptions a graphitic quartz schist (the "Dixon" of the State report) is known or is believed to underlie the contact-zones. This field relation is known through an understanding of the detailed stratigraphy of the Grenville sediments associated with the bedded graphite schists.[6] Thus I am of the opinion that the contact-zones and the true fissure veins of the Adirondacks are underlain by graphitic-bearing sediments whose graphite is organic in origin. There is good reason to regard the contact-zone graphite as due to the transfer of the organic graphite from the underlying sediments by means of the pegmatites. This in accord with Tilley's remark that bituminous matter in the sediments may be the source of the carbon which was oxidized at high temperatures by the igneous intrusives.[7]

Just how pegmatites could accomplish this transfer without the graphite, or some other form of carbon, passing into solution in the pegmatite matter is difficult to say. But the field facts seem to support such a contention; a conclusion opposed to Winchell's view that graphite is insoluble in silicate magmas.[8]

[4] *Op. cit.*, p. 168.

[5] *Op. cit.*, p. 194.

[6] Alling, H. L., "Some Problems of the Adirondack Precambrian," *Am. Jour. Sci.*, vol. XLVIII., 1919, p. 52.

[7] *Op. cit.*, p. 195.

[8] Winchell, ECON. GEOL., vol. 6, p. 222.

Thus I agree with Tilley in this matter. This view is strengthened by recalling the many instances of pegmatites cutting non-graphitic limestones and other barren sedimentary rocks and penetrating overlying paraschists *without* depositing graphite. It is realized, however, that the presence of graphite in the underlying rocks is not the only factor involved; the pressure, temperature and amount of water are to be considered.

The main point I wish to make is that wherever the contact or vein type of graphite occurs in the Adirondacks there is either actual proof of, or abundant evidence for, an underlying graphitic sediment from which the soda-granite pegmatites secured the graphite. This mineral was deposited in higher zones in pyroxene-scapolite rocks or along the margins of the pegmatites in contact with the country-rock. Where there was no underlying graphitic bed identical pegmatites produced no graphite. If Clark's theory that the source of the carbon is the CO_2 liberated from the limestones by the pegmatites, why is no graphite produced when non-graphitic beds lie in the path of the invading pegmatites? I think that the theory that Clark emphasizes cannot be held as of general application but that the presence of CO_2 secured from the calcareous sediments may have been a necessary reagent in the formation of a deposit of this type, though not the actual, or perhaps the major, source of the carbon of the graphite itself. I am in closer agreement with Tilley than with Clark regarding the actual source of the graphitic carbon.

The vein type is a closely related form. Graphitic beds are known to underlie the two properties where this kind of deposit occurs.[9] They are regarded as having been formed by similar transfer by pegmatitic solutions of hydrothermal character.

If this theory furnishes the correct explanation, then the usual classification of graphite deposits (including my own in the State report[10]) is misleading in that the contact and vein types have

[9] Alling, H. L., N. Y. State Mus. Bull, 199, 1918. Lead Hill, p. 31, "The Rowland mine," pp. 90–91.

[10] Clark has, though a typographical error mistated the general classification, placing the bedded deposits in the Northern area and the contact type in the Southern. These should be transposed.

been derived from *organic* graphite and transferred to higher beds by *inorganic* processes.

In 1917 I reached the conclusion that regional metamorphism alone was probably sufficient to account for the crystallization of amorphous carbon into flake graphite in the formation of the bedded graphitic quartz schists. Ferguson[11] questions this and suggests that the action of mineralizers accompanying granite intrusions are the principal factors in the conversion. He calls my attention to the fact that the Laurentian granite is always intricately involved with Grenville series; a fact I fully appreciate. The peculiarity of the Laurentian granite is its ability to soak and saturate foliated rocks (indicating a magma with a low viscosity) but not to produce contact effects or bring about other physical chemical changes. This is in strong contrast with the later Algoman syenite-granite (quartz nordmarkite) intrusives. Their chemical activity was great but their viscosity was high.

Slides of Grenville rocks lit-par-lit injected by the Laurentian granite show the granitic minerals in contact with unaffected sedimentary materials. The Dixon property lacks the Algoman granite series entirely and yet it is the chief mining district in the region.

I cannot believe that the mineralizers of the Laurentian granite have played such a major role in producing the flakes as Ferguson suggests. On the Graphite Products Corporation's property, Algoman granite pegmatite stringers have locally increased the size of the flakes but have produced an ore whose variability makes a difficult milling ore. The best ore is free from igneous material.

HAROLD L. ALLING.

DEPARTMENT OF GEOLOGY,
UNIVERSITY OF ROCHESTER,
ROCHESTER, N. Y.

[11] Ferguson, H. G., review of the State Report, ECON. GEOL., vol. 14, 1919, p. 574.

REVIEWS

Geology of Petroleum. By W. H. EMMONS. New York, McGraw Hill Hill Book Co., 1921.

The author of this book has held closely to his subject "The Geology of Petroleum." Intended primarily as a text for students trained in the general principles of geology no space is devoted to building a foundation for the subject and none is given to such matter as the technology of petroleum, drilling methods, or oil field management. One may wish that a supplemental chapter had been devoted to methods of geologic field work and another to subsurface mapping instead of the all too brief chapter of nine pages entitled maps and logs, inserted between two such closely related chapters as Origin of Petroleum and Accumulation of Petroleum.

The book as a whole, however, is well organized and the discussion is in the author's usual clear style of presentation. Illustrations, 254 in number, are well chosen and many of them are from sources not accessible to the average reader. References are faithfully recorded and all pertinent literature up to about the middle of 1920 seems to have been covered.

An introductory chapter on the uses, geologic, and geographic distribution of petroleum is followed by chapters on surface indications, openings in rocks, association of petroleum and salt water, reservoir rocks and covering strata, some properties of petroleum and gas, origin, maps and logs, accumulation, structural features of reservoirs, deformation of petroliferous strata, metamorphism of petroleum by dynamic agencies, and gas pressure and oil recovery. These general chapters are followed by descriptions of more important oil fields of the United States, Canada and Mexico. Briefer descriptions cover other countries, grouped in the main by continents.

There is little in the book to criticize and much to commend. As a text it is much superior to any other available and contains comparatively few inaccuracies. A better structural map of the Eldorado field might have been used: The deep production in the Wilcox sand could have been more adequately discussed and its relations to the Mareland sand outlined. There are also minor typographical errors, as for example the spelling of Nacatoch on p. 356, but these are comparatively few.

The combining of pools producing from late Paleozoic and Cretaceous strata in Texas is not warranted in a systematic treatment although such districts are included by current usage under the term Mid-Continent Fields. There is as much justification for considering the Gulf Cretaceous a separate unit as there is for separating off the Gulf Coast fields. The reviewer believes that failure to separate the Mid-Continent Field into northern and southern parts with reference to the Arbuckle and Wichita uplifts is fully warranted. Indeed it is to be hoped that for the United States some one will prepare a treatise grouping the producing fields closely by the age of the enclosing beds rather than geographically. In this way only is it possible to make the utmost use of the paleogeographic maps in the important study of the origin of petroleum and thus lend greatest aid to those searching for it. Such a treatment would involve extensive research and is possibly not to be expected in a textbook. It would, however, benefit the study of petroleum deposits in a manner comparable to Lindgren's genetic treatment of ore deposits and even though a first attempt would surely be inadequate it would stimulate discussion and observation.

In brief "Geology of Petroleum" is an excellent treatise of the subject and can be highly recommended as a textbook for a university course and as a reference book for the professional geologist. To the latter the large number of footnote references will be exceedingly valuable.

J. B. UMPLEBY.

NORMAN, OKLAHOMA.

Structural and Field Geology, for Students of Pure and Applied Science. By JOSEPH GEIKIE. Fourth Edition, revised. 454 pp., 69 plates and 159 figs. D. Van Nostrand Co., N. Y., 1920. Price $7.50.

The fourth edition of this handsome volume differs from the second edition mainly in the addition of 12 pages of text, 13 plates and 15 figures, and in the price. The text has been revised by Robert Campbell of Edinburgh, but the revision is limited almost entirely to a few definitions, and to the description of rocks and rock-forming minerals. All the magnificent plates of the earlier editions have been retained and to these have been added other plates equally as good and fully as instructive. The additional figures are principally of folds. The book is well printed on heavy paper and is apparently strongly bound.

Although departing widely in character from the various practical and theoretical Field and Structural Geologies with which we are so familiar, this new edition of Geikie's volume will be acceptable to all teachers of geology as the best *descriptive* field geology yet published. It pictures the phenomena one observes in the field and explains them in

clear and simple language, leaving to other books the tasks of discussing the mechanics of the forces producing them and of developing the methods for working out their details. A thorough study of its pages should prepare the student for a better appreciation of the value of such books as Lahee's Field Geology and Leith's Structural Geology, than is usually the case.

W. S. BAYLEY.

SCIENTIFIC NOTES AND NEWS[1]

F. H. MOFFIT AND S. R. CAPPS, of the U. S. Geological Survey, are in Alaska, engaged in making topographic and geologic surveys of the petroleum districts of Iniskin and Cold Bay, respectively.

D. B. DOWLING, of the Canadian Geological Survey, and party, are in the Mackenzie River district, making a survey of the country from the mouth of the Peace River to the vicinity of the Arctic Circle.

L. C. GRATON, of Cambridge, Mass., is at Calumet, Mich., for the summer.

R. VAN A. MILLS, of the U. S. Bureau of Mines, is investigating oil field water troubles in the Mid-Continent and California fields.

W. T. LEE, of the U. S. Geological Survey, is engaged in stratigraphic studies for oil and gas work in Wyoming.

H. RIES is spending the summer in Kentucky making some investigations of the clay and shale deposits for the Kentucky Geological Survey.

M. R. CAMPBELL has been in the field since July 19. He first went to Oak Creek, Colorado, then to Idaho, Montana and Utah, inspecting field work in those States.

D. D. SMYTHE, Instructor in Economic Geology at Cornell University, has accepted a position as Geologist with the Cerro de Pasco Copper Corporation, of Peru.

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

ALFRED H. BROOKS, of the U. S. Geological Survey, sailed early in August for Seward, Alaska.

OLAF P. JENKINS, of the State College of Washington, is in charge of the field work for the Washington Geological Survey, and is investigating road materials, the Grand Coulee as a reservoir site, and the iron ores of Washington in relation to the possible manufacture of iron and steel.

R. C. MOORE, of the U. S. Geological Survey, and party, are engaged in field work in Garfield and Kane counties, Utah.

EDWIN B. HOPKINS, consulting geologist and petroleum engineer, announces the removal of his offices from 512 Fifth Avenue to the Cunard Building, 25 Broadway.

G. H. DOANE, of Columbia University, has been appointed instructor in Economic Geology at Cornell University.

PHILIP N. MOORE, mining engineer, has returned to his practice in St. Louis, Mo., after serving for two years on the War Minerals Relief Committee.

FRED SEARLS is expected to return to San Francisco from China in July.

FREDERICK G. CLAPP and The Associated Petroleum Engineers have moved their offices from 120 Broadway to Suite 2025, 30 Church Street, New York City.

W. E. CAMERON, deputy chief geologist of Queensland, has been appointed mining geologist to the Federated Malay States.

C. E. SIEBENTHAL, geologist of the U. S. Geological Survey, was recently engaged in geologic work in the Joplin District, Missouri.

CHARLES D. WALCOTT, secretary of the Smithsonian Institution, was recently awarded the Mary G. Thompson gold medal by the National Academy of Sciences "for distinguished research in geology and paleontology."

J. Ross CORBIN, mining engineer of Philadelphia, has been commissioned by the State Geologist of Pennsylvania to study the iron-ore resources of that State.

A. A. LEECH, geologist for the Phelps Dodge Corporation, Tyrone, N. M., has resigned and is going to Mexico.

J. MACKINTOSH BELL has returned from London to Almonte, Ontario.

WALTER E. GABY has been appointed geologist to the Santa Gertrudis Company, at Pachuca, Mexico.

FREDERICK B. HYDER, formerly valuation engineer of the Income Tax Unit, Bureau of Internal Revenue, has resumed practice as mining and metallurgical engineer, with offices at 460 Montgomery Street, San Francisco.

A. S. EAKLE, professor of mineralogy in the University of California, is in charge of the university extension course in mineralogy, conducted by correspondence.

C. L. NELSON is taking a year's leave of absence from the U. S. Geological Survey, and has been assigned to work on the island of Timor, in the East Indies, by the Sinclair Exploration Co., with which he is now connected.

JAMES HOPKINS, mining engineer, who has been working in the diamond fields of the Belgian Congo, is now in Ramey, Penna.

H. C. COOKE, of the Geological Survey of Canada, will teach geology in place of Dr. J. Austin Bancroft, at McGill University, Montreal, Quebec, next year.

A. D. COMBE, of Sydney, N. S. W., has been appointed assistant geologist in Uganda, Eastern Africa, under the British Colonial office.

A. F. MELCHER has been studying porosity of oil horizons in eastern Oklahoma.

ARTHUR CLARK TERRILL has taken up his new duties as professor of mining at Pei Yang University.

STUART ST. CLAIR, consulting geologist, has moved his office from Chicago, Ill., to 55 Liberty Street, New York, where he will devote most of his time to foreign oil work.

CHARLES BUTTERS has returned to New York from Nicaragua, where he stopped on his return from Chile.

THEODORE A. LINK, geologist of Imperial Oil, Ltd., has left Edmonton, Alta, for the Fort Norman field, in Mackenzie River district.

M. I. GOLDMAN has finished his study of sediments and salt domes in Texas and Louisiana and has returned to Washington.

WILFRID KILIAN, professor of geology at the University of Grénoble in the Dauphin, France, has been awarded the Gaudry gold medal, the highest distinction of the Société Géologique de France.

M. Y. WILLIAMS, professor of paleontology in the University of British Columbia, Vancouver, B. C., is in charge of a party sent out by the Canadian Geological Survey to make a survey of the Mackenzie River district.

THEODORE CHAPIN has returned from work in oil geology in the Tampico region, Mexico, and is now engaged in revising a report on the Ketchikan district, southeastern Alaska, for the U. S. Geological Survey.

FRANK REEVES, of the U. S. Geological Survey, is in central Montana, where he is studying oil and gas.

JOHN NEWSON has returned from the Malay States.

BRADLEY STOUGHTON has resigned as Secretary of the American Institute of Mining and Metallurgical Engineers.

VICTOR C. SVIMONOFF, a petroleum engineer of the Baku oil fields, has returned from Russia, after an escape from the Bolshevists. He is at present at 370 West 120th Street, New York.

R. S. KNAPPEN, of the University of Kansas, is engaged in mapping and examining the oil and gas possibilities of Grant County, Oklahoma, for the U. S. Geological Survey.

DAVID B. REGER, assistant geologist of the West Virginia Geological Survey, is spending the field season in Grant and

Mineral Counties, undertaking work for a Geological Report on the area mentioned.

J. B. TYRRELL, mining engineer and economic geologist, has been elected one of the vice-presidents of the American Association for the Advancement of Science, and Chairman of the Engineering Section. The A. A. A. S. holds its next annual meeting in Toronto from December 27 to December 31.

F. C. CALKINS, of the U. S. Geological Survey, this summer completed a survey of the Big Cottonwood district, Utah.

J. J. O'NEILL has been appointed acting assistant professor of geology at McGill University, Montreal, during the absence of J. A. Bancroft.

J. R. FINLAY, of New York City, recently made an examination of the Chapin mine at Iron Mountain, Michigan, for the Chapin Estate.

CYRIL W. KNIGHT, assistant provincial geologist, spent the summer at Cobalt, Ontario, making an underground study of the silver mines.

FREDERICK F. SHARPLESS has been elected to succeed Bradley Stoughton as secretary of the American Institute of Mining and Metallurgical Engineers.

S. H. DOLBEAR has gone to Ontario on professional business. He is also establishing an office in New York.

BROKAW, DIXON, DONNELLY, GARNER AND MCKEE, geologists and petroleum engineers, have moved their office from 90 West Street to 120 Broadway, New York City.

C. MINOT WELD, DONALD M. LIDDELL AND PAUL H. LAZENBY announce that they have formed a partnership under the name of Weld, Liddell and Lazenby, as consulting engineers and economists, at 2 Rector Street, New York City.

BENJAMIN D. STEWART has been reappointed by Governor Thomas Riggs as territorial mine inspector for Alaska.

W. H. CRAGO, FRANK HUTCHINSON, W. R. APPLEBY, W. R. EMMONS, WARREN J. MEADE AND L. D. DAVENPORT sailed from

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Seattle in June for China to make a geological examination and report for the South Manchuria Railroad Company, covering the iron and coal deposits owned by the company in the vicinity of Anshan and Mukden, Manchuria.

FREDERICK H. MINARD has moved his offices to the New Liggett Building, 47 East 42d Street, New York City.

BURR MCWHIRT, petroleum geologist, announces his resignation as valuation engineer in the oil and gas section of the Income Tax Unit, Washington, D. C., to become associated with J. C. Dick in the valuation of mines, oil and gas properties, and technical questions involved in the federal income tax laws.

G. R. MACCARTHY, of Cornell University, has been appointed Instructor at Williams College.

WARREN D. SMITH, of the Philippine Bureau of Mines, has sent out a press bulletin (No. 97) to correct the garbled and exaggerated press statements pertaining to petroleum in the Philippines. He points out that a high-grade petroleum with a source in foraminifera shale and similar in character and occurrence to the East India petroleum has been proved, but that the quantity is unknown. "Wildcat" work by competent and financially able concerns would be justified.

AN announcement of the Committee of Organization of the International Geologic Congress states that the next session of the Congress will be in Belgium, during the latter half of August, 1922. This is adhering to the original place of meeting offered and accepted at the last session, held in Canada, in 1913. Additional notices will be issued from time to time, and those geologists that are interested would do well to send their names and addresses to The Secretary, Congrès Géologique International, Service géologique de Belgique, Palais du Cinquantenaire, Brussels, Belgium.